Degradation Properties of Bioresorbable Material Candidates for Congenital Heart Defect Repair

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Abstract

The goal of this project is to investigate the use of bioresorbable materials for congenital heart defect repair. This investigation focused on the in vitro degradation over eight weeks of several biodegradable polymers including: Poly (L-lactide) or PLLA, 70:30 Poly (L-lactide)-Polycaprolactone or PLLA/PCL and Polyglycolide or PGA. Since surface area can affect degradation rates several morphologies of these polymers were included in the study such as knits, films, felts, electrospun materials and sponges. The degradation was characterized by: tensile testing, scanning electron microscope (SEM) visualization, differential scanning calorimetry (DSC) and gel permeation chromatography (GPC). Results of these tests do not directly provide recommendation for specific materials for use as implantable, bioresorbable materials but they do confirm that the combination of chemical composition and material morphology significantly affect the degradation rate as measured by changes in molecular weight with time. This finding supports the possibility of fine tuning manufacturing processes of these materials to obtain a specific degradation profile. PLLA film material 3 was the only material tested that maintained its peak stress and peak strain behavior over the 8 week degradation time period. This does not necessarily rule out the other materials as long as they maintain mechanical integrity over the required time period. In addition, the changes in molecular weight (but not stress and strain behavior) over time were significantly affected by the type of degradation environment the material was placed in, static vs. agitated or dynamic. The importance of the degradation rate and mechanism for this application is extremely important so the inclusion of some form of agitation in future degradation experiments is recommended. Finally, the degradation environment in this experiment was relatively inert and testing with digestive enzymes or other blood components is also recommended.

List of Tables

List of Figures

Introduction

In fetal circulation there is an opening between the atria in the heart allowing blood flow to bypass the lungs and this opening usually closes at birth. There are several types of congenital heart defects that occur when natural closing of this shunt between the atria fails. An atrial septal defect (ASD) is a congenital defect consisting of a physical hole between the atria and is usually immediately apparent. A patent foramen ovale (PFO) is a less obvious residual tunnel, or opening between flaps of tissue, between the atria. A PFO can have a 1 to19 mm slit width (Hara et al., 2005; Kutty, Sengupta, & Khandheria, 2012) but the average PFO diameter is 3.4 mm in the first ten years of life and becomes 5.8 mm by approximately 100 years of age (Hara et al., 2005). Historically, PFO often goes undiagnosed but autopsy studies have shown that PFO is thought to be present in 9% to 25% of the adult population (Boucek, 2005; Fisher, 1995; Hara et al., 2005).

Recently and still controversial (Davis et al., 2013; Kutty et al., 2012), PFO has been linked to occurrences of cryptogenic stroke, migraine, visual aura and sleep apnea (Kutty et al., 2012; Mojadidi, Khessali, Gevorgyan, Levinson, & Tobis, 2012: Guchlerner et al., 2012). There are studies suggesting that closure of PFO has reduced the frequency and intensity of migraine (Rigatelli et al., 2012; Nagpal et al., 2013) as well as visual aura (Khessali, Mojadidi, Gevorgyan, Levinson, & Tobis, 2012; Mojadidi et al., 2012) but whether PFO closure is more effective than current treatments for cryptogenic stroke is still unclear (Kutty et al., 2012).

There are several transcatheter delivered medical devices that have been or are used to close congenital heart defects such as ASD and PFO. No devices are currently approved by the FDA for PFO closure and instead devices are used off label in these instances. Only two devices are approved for ASD closure as of 2012: the HELEX™ Septal Occluder and the AMPLATZER™ Septal Occluder (Medical policy: Closure devices for patent foramen ovale and atrial septal defects (ASD), 2012; The Cleveland Clinic

Foundation, 3/30/2012). The AMPLATZER™ Septal Occluder is made up of two disks connected by a waist, all made of nitinol metal mesh, and the disks contain polyester fabric (AMPLATZER TM septal occluder, 2012). The HELEX™ Septal Occluder is made of ePTFE (expanded polytetrafluoroethylene) and nitinol metal wire (GORE (R) HELEX (R) septal occluder, 2012; Proprietary ePTFE technology form gore, 2012).

Along with the possible health benefits mentioned previously there are health risks to having a permanently implanted device. These devices can be implanted at an early age and due to the relatively recent use of these devices long term studies are not available for permanently implanted materials in this location of the heart (Jux et al., 2002). In addition, non-bioresorbable materials do not grow with a patient's tissue (Jux et al., 2002). Permanently implanted materials in the atrial septum could also interfere with future use of non-invasive heart surgery techniques requiring trans-septal crossing (Jux, Bertram, Wohlsein, Bruegmann, & Paul, 2006), are a possible source of thrombosis and pose a risk of infection or tissue erosion (Jux et al., 2002).

It has also been noted that, "the device itself may be dispensable once the defect is closed and covered by a complete and firm layer of ingrown, endogenous "repair" tissue" (Jux et al., 2006). This may be especially appropriate in the case of PFO closure where there is no physical hole for tissue to grow into but a tunnel that needs to be closed (Jux et al., 2006). This would suggest the use of bioresorbable materials for PFO closure (Jux et al., 2002; Jux et al., 2006). A fully bioresorbable device may be ideal but the initial step of incorporating a bioresorbable fabric with a flexible metal frame seems a logical first step so only fabric biomaterials will be investigated in this study.

Characterizing the Cardiac Environment

If a device is to be placed within the extremely dynamic environment of the heart there are a number of environmental factors to be aware of when selecting a biomaterial fabric including but not limited to: atrial septal tissue histology, inter-atrial pressure differences, atrial septal wall movement during the heartbeat cycle, tissue mechanical properties, immune response and tissue in-growth and endothelialization rates. These topics will be briefly discussed here.

Atrial Septal Tissue Histology: Long term implantation of a device in the heart, especially one that is meant to eventually degrade away, would optimally require an implanted material that mimics or is compatible with the existing tissue. There are always individual differences when it comes to anatomy but the atrial septum is primarily composed of muscle tissue along with amounts of fibrous and adipose tissue (Hara et al., 2005; Patten & Patten, 1931). At 1-2 months of age fibrous or connective tissue growth begins and by 8-9 months of age connective tissue has greatly increased with no significant difference in the amount of muscle tissue (Patten & Patten, 1931). These changes in tissue suggest that the natural mechanism of PFO closure utilizes connective tissue growth. Supporting this, case-by-case observations also support closure via fibrous tissue growth (Nir, Driscoll, & Edwards, 1994; Perloff, 1971; RAO & SISSMAN, 1971). In healthy individuals, the atrial surfaces such as the atrial septum are also covered with a layer of endothelial cells that act as a barrier between tissue and blood that prevents blood clots (Hara et al., 2005).

Inter-Atrial Motion and Pressure Differential: A medical device implanted within the atrial septum will be exposed to motion of the atrial septum as well as the inter-atrial pressure difference. Variations in anatomy allow for a large range of atrial septal motion but “a protrusion of the aneurysm >10 mm beyond the plane of the atrial septum into either the right or left atrium” is considered an atrial septal aneurysm in a study by Mügge et al. who noted that a specific definition is somewhat arbitrary and listed other definitions that have been used (Mügge et al., 1995). This group also noted that this definition is one of the broader, more inclusive definitions (Mügge et al., 1995). This would suggest that anything up to about 10 mm movement of the atrial septum is considered normal. However, atrial septal aneurysm is associated with atrial shunting, as

Mügge et al. reported that 106 of the 195 atrial septal aneurysm cases were concurrent with atrial shunting. This means that atrial septal deviations of about 18-23 mm may be involved in PFO closure (Mügge et al., 1995). In addition to movement, the device material and anchoring system must remain intact and seated in the atrial septum while experiencing a slight pressure differential between the atria. The pressure differential in a typical human heart is approximately in the order of 0-19 mmHg (Kupferschmid & Lang, 1983; Percy et al., 1985; Davidson et al., 2008).

Table 1: Tissue mechanical properties

Substance	Tensile Strength	Young's Modulus
Human cardiac tissue (Chen et al., 2008)	0.003-0.015MPa (3-15 kPa)	0.02 – 0.5 MPa
Fibrous Collagen (Chen et al., 2008)	1-7MPa	2-46 MPa
Collagen Gel (bovine) (Chen et al., 2008)	0.001-0.009 MPa (1-9 kPa)	0.002–0.022 MPa

Immune Response: Common immune system responses for current devices used for PFO and ASD closure in human case studies as well as animal studies were examined to provide a standard for comparison for any future work with biodegradable materials. In a study conducted by Sigler and Jux on looking at long term implantation of the Amplatzer and Starflex devices in animals and human case studies they report chronic mild inflammation associated with the polyester material of these devices "with some interindividual variation, the presence of multinucleated giant cells and lymphocytic infiltrates persisted and was observed also in the longest-term implants (1-year animal group, patient 12 after 4 years) without a tendency to diminish in its extent" (Sigler & Jux, 2007). Another study conducted by Jux et al. comparing the BioStar device made of heparin coated acellular collagen with the Starflex device had similar findings for the polyester material but "the BioSTAR matrix led to a transient, focally circumscribed mild-to-moderate lymphocytic immune response" (Jux et al., 2006). This finding would support the use of biocompatible and biodegradable materials for congenital heart defect repair.

Tissue in-growth: Tissue in-growth and endothelialization rates of current devices in human case studies and animal studies were also investigated to use as a standard for comparison. In general, studies report substantial endothelialization and tissue ingrowth at time points around thirty to ninety days (Jux et al., 2006; Sigler & Jux, 2007; Zahn, Wilson, Cutright, & Latson, 2001). The study by Sigler and Jux also noted that complete endothelialization of devices (including the metal frames) is approximately three to five months after implantation (Sigler & Jux, 2007). However, Chessa and colleagues share a case study where one side of an Amplatzer device remained uncovered by an endothelial cell layer after approximately two years implantation (Chessa, Butera, Frigiola, & Carminati, 2004). Studies involving the BioStar degradable device show that "longitudinal splits and fraying at the terminal edges of the collagen matrix allowed for infiltration of the matrix with fibroblasitc and monoculear lymphoid cells" at approximately thirty days after implantation and "calculated that approximately 90% of all implanted ICL material had been resorbed after two years in vivo" (Jux et al., 2002). Taken together, these findings support the idea that a degradable material will allow for tissue ingrowth and this ingrowth, and corresponding partial material degradation, should occur within the first thirty days after implantation. It is also important that the septum and bioresorbable device material retain their integrity until complete endothelialization and tissue ingrowth, somewhere on the order of five to twenty-four months.

Biomaterials Search and Selection

Materials selection began with an literature search of bioresorbable materials candidates and after an initial search there were a number of bioresorbable materials considered for this study including: manufactured collagens, Poly (L-lactide) (PLLA), poly(lactic-coglycolic acid) (PLGA), Poly(ester-urethane) (PEUUs), Poly (L-lactide)-Polycaprolactone (PLLA/PCL), PLGA combinations with PLLA fabric and Polyglycolide (PGA).

The materials previously listed were further investigated with a focus on the compatibility with the environmental characteristics discussed above. Next a meeting was held with a medical device company that this study partnered with. The material selection process focused on degradation characteristics, cytotoxicity/immune response, material properties, current FDA standing and manufacturability/obtainability of the bioresorbable materials listed above. Within that meeting three materials were selected for biodegradation testing: Poly (L-lactide) (PLLA), Poly (L-lactide)-Polycaprolactone (PLLA/PCL) and Polyglycolide (PGA). In addition to these three chemical compositions, several morphologies of the first two of these materials were selected to determine how tunable the degradation characteristics were by the slight variations in surface area resulting from different manufacturing processes.

Biodegradation Study

The heart is such a dynamic environment there was concern that fluid flow rates/agitation may affect degradation so two environmental conditions were selected for this study. The first is a stagnant environment (considered a fairly standard condition for degradation tests and complies with ASTM standards) and an agitated condition where sample vials were placed in an incubator shaker set at 80 rpm. The time points of interest were 2 weeks, 4 weeks, and 8 weeks which were meant to correspond to particular points of endothelialization and cell in-growth behavior. The following items were recorded for each of the materials at the different degradation time points and, where appropriate, compared to data collected at a baseline for each material. Another option for the partnering medical device company would be to look at the behavior of their Angioseal Anchor medical device in the specific conditions performed in this study and compare that to its known behavior in vivo as they have access to data on its in vivo performance and can subject it to the same in vitro conditions of our study for comparison.

Degradation Characterization Measures:

1. Mass Measurement – the percent of mass lost relative to initial mass provides “macro” level degradation characterization
2. Tensile Testing - peak stress (or ultimate stress) and peak strain (engineering stress and strain) provides information on if and how mechanical properties of the materials change with degradation
3. Gel Permeation Chromatography (GPC) - molecular weight measurement provides molecular level degradation characterization
4. Differential Scanning Calorimetry (DSC) – measures of glass transition, melting and crystallization temperatures (Tg, Tm, and Tc respectively) provides information on how molecular weight change relates to physical properties of materials and insight into molecular bonding behavior
5. Scanning Electron Microscopy (SEM) - used for visual characterization of surface degradation

Table 2: Degradation study materials information

Material	Manufacturer	Composition	Type	Pore Size	Porosity	Thickness
PLLA Candidates						
1	Proxy	PLLA (Poly (L-lactide))	Film	0.3 mm	15%	0.14mm
2	Proxy	PLLA (Poly (L-lactide))	Film	0.35 mm	20%	0.11mm
3	Proxy	PLLA (Poly (L-lactide))	Film	0.7 mm	50%	0.20mm
4	Concordia	PLLA (Poly (L-lactide))	BIOFELT	N/A	(200 mg/cc)	0.3 mm
PLLA/PCL Candidates						
5	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Electrospun	0.6 mm	40%	~0.35mm
6	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Electrospun	N/A	65%	0.08mm
7	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Electrospun	0.5 mm	70%	0.08mm
8	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Film	0.65 mm	40%	0.11mm
9	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Film	0.7 mm	50%	0.08mm
10	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Film	0.75 mm	55%	0.11mm
11	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Film	0.5 mm	55%	0.16mm
12	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Film	0.75 mm	60%	0.08mm
13	Proxy	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Film	0.55 mm	70%	0.14mm
14	Kensey-Nash	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Sponge	N/A	0.45 g/cm^3	0.27 mm
15	Kensey-Nash	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Sponge	N/A	0.73 g/cm^3	0.24 mm
16	Kensey-Nash	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Sponge	N/A	0.70 g/cm^3	0.16 mm
17	Kensey-Nash	70:30 PLLA/PCL (Poly (L-lactide)-Polycaprolactone)	Sponge	N/A	0.43 g/cm^3	0.15 mm
PGA Candidate						
18	Concordia	Polyglycolide (PGA)	Knit	N/A	N/A	~0.21 mm

Materials 1, 2 & 3: PLLA Films

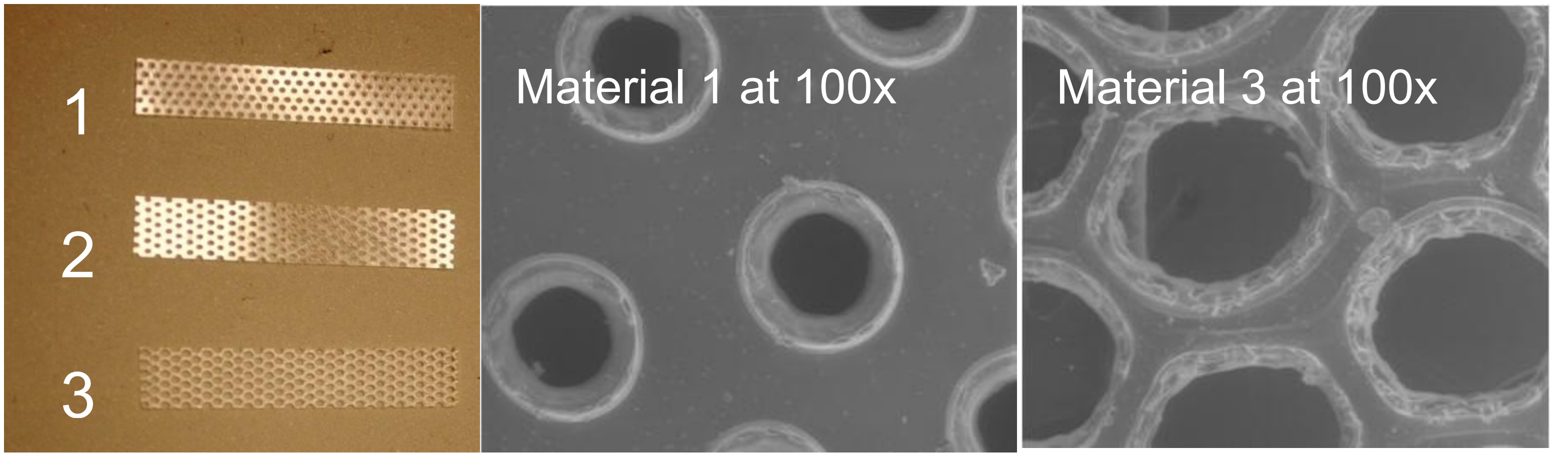
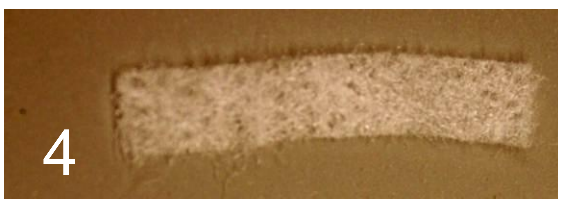


Figure 1: **Material 1: Proxy PLLA Film - 0.3mm pore diameter, 15% porosity, 0.14mm thickness**
Material 2: Proxy PLLA Film - 0.35mm pore diameter, 20% porosity, 0.11mm thickness
Material 3: Proxy PLLA Film - 0.7mm pore diameter, 50% porosity, 0.20mm thickness

Material 4: PLLA Electrospun 'BIOFELT'



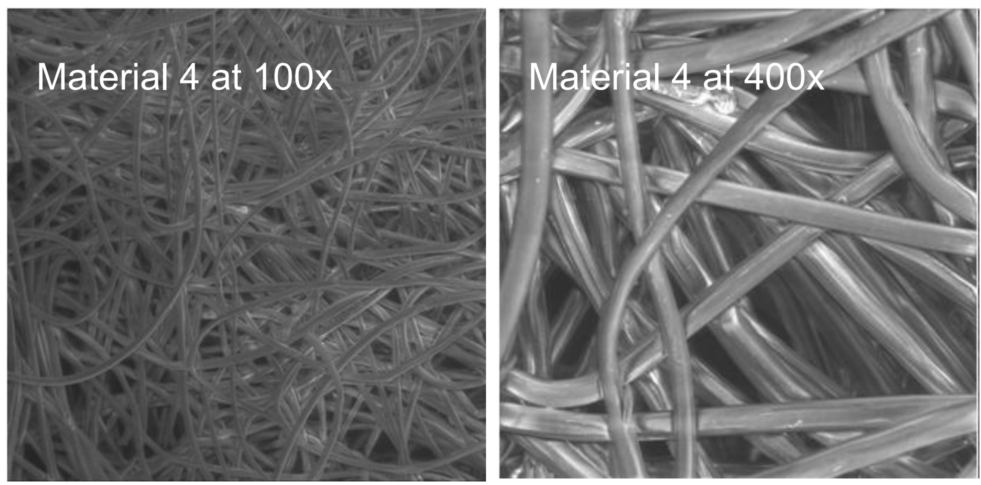


Figure 2: Material 4: Concordia PLLA Biofelt 200 mg/cc, 0.3mm thickness

Materials 5, 6 & 7: Electrospun PLLA/PCL

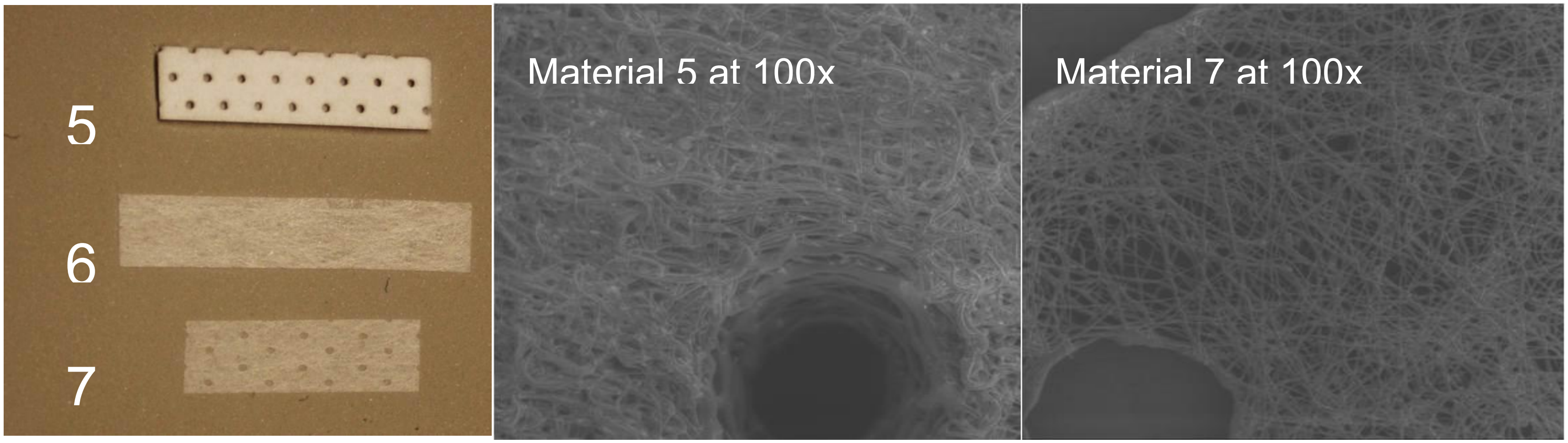


Figure 3: **Material 5: Proxy Electrospun 70:30 PLLA/PCL - 0.6mm pore diameter, 40% porosity, 0.35mm thickness**
Material 6: Proxy Electrospun 70:30 PLLA/PCL - no pores, 65% porosity, 0.08mm thickness
Material 7: Proxy Electrospun 70:30 PLLA/PCL - 0.5mm pore diameter, 70% porosity, 0.08mm thickness

Materials 8, 9, 10, 11, 12 & 13: PLLA/PCL Films

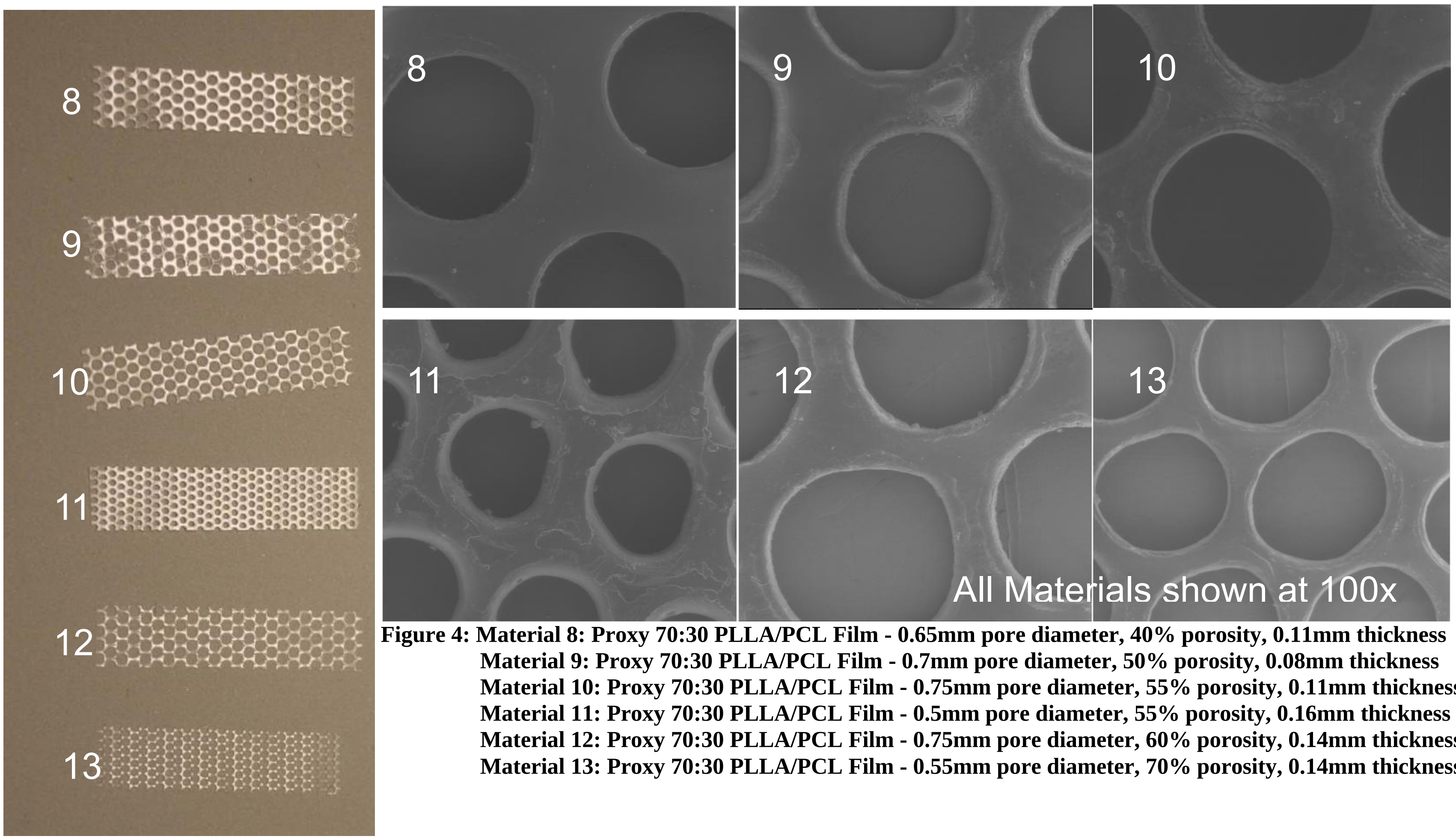


Figure 4: Material 8: Proxy 70:30 PLLA/PCL Film - 0.65mm pore diameter, 40% porosity, 0.11mm thickness
Material 9: Proxy 70:30 PLLA/PCL Film - 0.7mm pore diameter, 50% porosity, 0.08mm thickness
Material 10: Proxy 70:30 PLLA/PCL Film - 0.75mm pore diameter, 55% porosity, 0.11mm thickness
Material 11: Proxy 70:30 PLLA/PCL Film - 0.5mm pore diameter, 55% porosity, 0.16mm thickness
Material 12: Proxy 70:30 PLLA/PCL Film - 0.75mm pore diameter, 60% porosity, 0.14mm thickness
Material 13: Proxy 70:30 PLLA/PCL Film - 0.55mm pore diameter, 70% porosity, 0.14mm thickness

Materials 14, 15, 16 & 17: PLLA/PCL Sponge

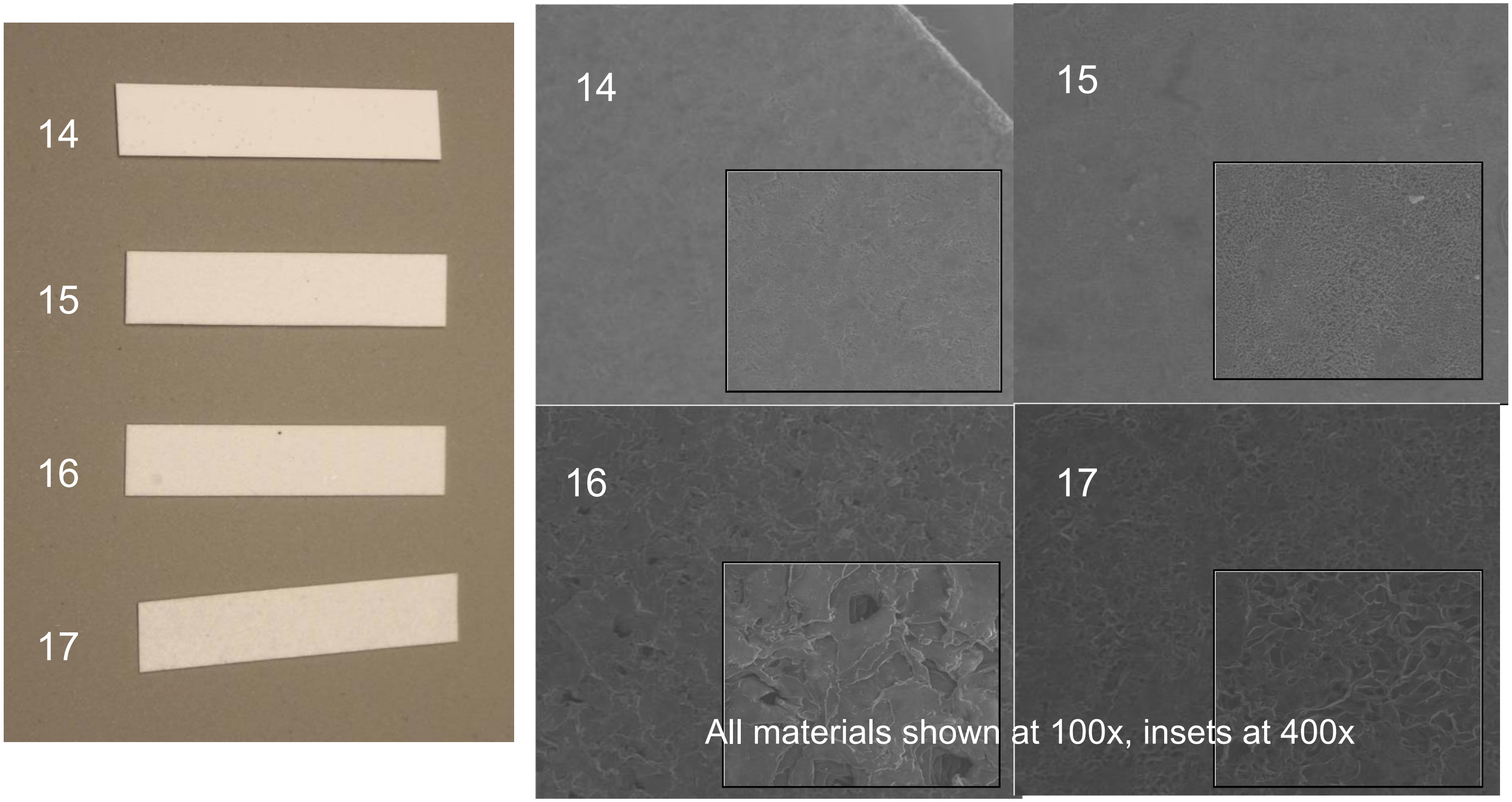


Figure 5: **Material 14: Kensey-Nash PLLA/PCL Sponge - 0.27mm thickness, 0.45g/cm^3**
Material 15: Kensey-Nash PLLA/PCL Sponge - 0.24mm thickness, 0.73g/cm^3
Material 16: Kensey-Nash PLLA/PCL Sponge - 0.16mm thickness, 0.70g/cm^3
Material 17: Kensey-Nash PLLA/PCL Sponge - 0.15mm thickness, 0.43g/cm^3

Material 18: PGA Warp Knit Mesh

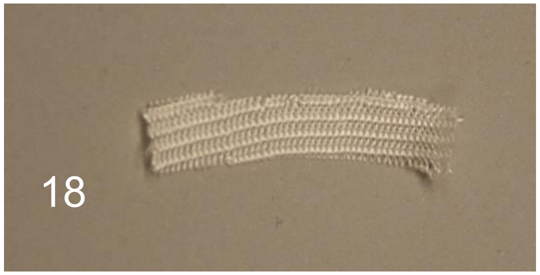
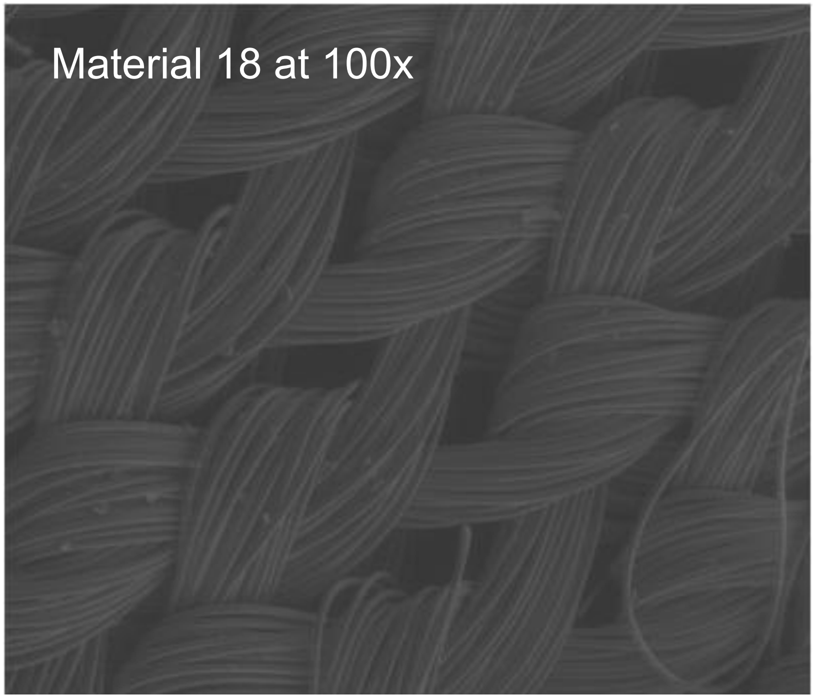
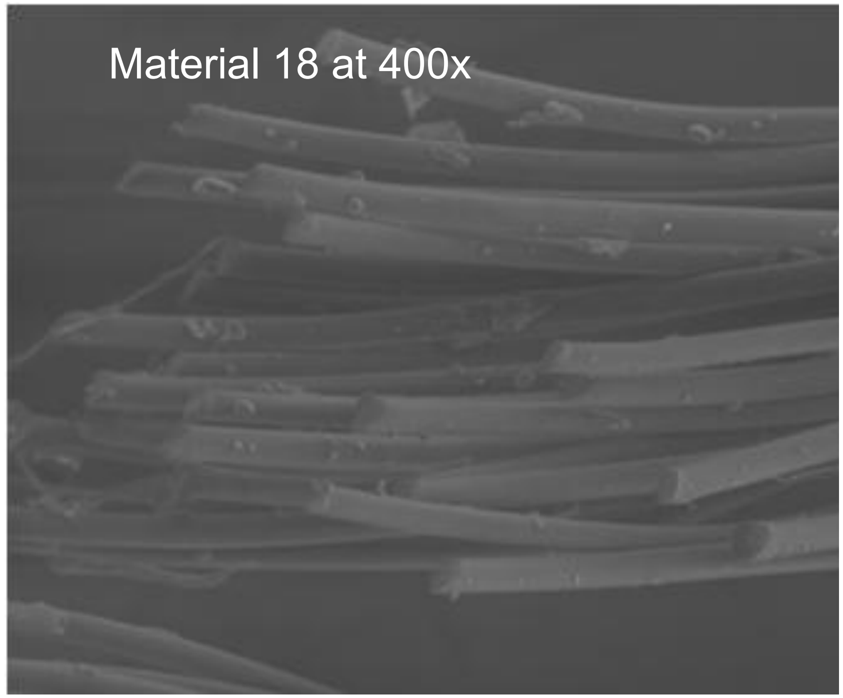


Figure 6: Material 18: Concordia PGA Warp Knit Mesh - approximately 0.02mm thickness, Knit pattern: 1-0-1/1-2-1





Methods

Sample Preparation and Handling

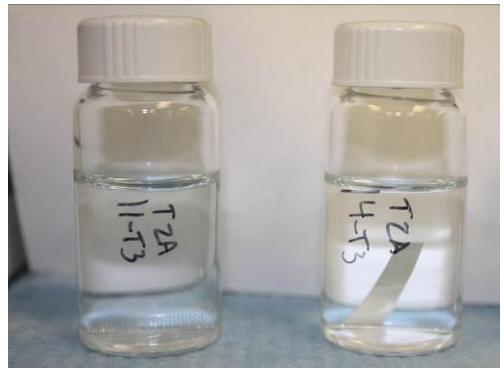


Figure 7: Samples shown in testing vials

An effort was made to minimize the amount of time the samples spent in an open air environment between opening the packaging and placing the samples in solution to minimize exposure to environmental moisture. Gloves were worn by the investigators while handling the samples to protect them from skin oils or other contaminants. Vials (20 mL) of the pH buffered saline solution (0.01 M phosphate buffer and 0.01 NaCl with pH of 7.4) were prepared and labeled with a marker. Next the sample packaging was opened and the samples were cut with two special rolling cutting devices (4mm and 20mm widths) that could make consistent cuts so that the samples were uniform sizes. Once cut, samples (sample mass ranging from approximately 0.012g to 0.015g) were placed in the vials, submerged in the solution, and sealed by screwing on the cap. Half of these samples were then placed in an incubator at body temperature (37 °C ± 2 °C), the stagnant degradation environment (environment 1), and the other half of the samples were placed in an incubator/agitator at 37 °C ± 2 °C and at 80 RPM, the agitated degradation environment (environment 2). At each time point (2 weeks, 4 weeks, and 8 weeks) the appropriate samples were removed from the buffered solution, rinsed with de-ionized water, placed in a cassette, dried in a Lyophilizer overnight and frozen (if testing did not occur) immediately to arrest any further degradation. The pH of one sample from each of the materials was tested periodically (approximately every two weeks) with pH indicator strips (colorpHast by EMD) and if the solution was too acidic (pH of 6 or less) more buffered saline solution was added to the corresponding group of samples.

Table 3: Sample quantities and sample lengths for different types of testing (for each material)

	Tensile (30 mm)	GPC (20 mm)	DSC (20 mm)	SEM (10 mm)
Agitated	3	3	3	2
Stagnant	3	3	3	2
# samples for each material and each test	6	6	6	4
# samples for all time periods	24	24	24	16
Total # of samples for each material				88

Percent mass lost

The initial mass of 3 samples from each of the two environments at all three time points were recorded with a digital scale (mg). At each time point the appropriate samples were removed, dried and frozen. Then, each sample was re-weighed on the digital scale (mg). The percent mass lost relative to the initial, or baseline mass, of each individual sample is then calculated.

Tensile Testing

Procedure: Samples soak in DI water for several minutes, are loaded into and Instron Tensile Tester 5542 (Mitutoyo12 mm gauge length) with sandpaper enhanced grips and pulled at a rate of 20 mm/min until failure. Note: Due to size constraints 30 mm x 4 mm pieces of material were used in tensile testing.

Differential Scanning Calorimetry (DSC)

Samples for DSC were cut into small squares and as many as would fit were placed in the standard aluminum pans (goal weight between 3mg and 5mg) and used for DSC testing. The samples were then run with the TA Instruments Thermal Analysis - DSC Standard Cell RC with the appropriate profile for each material composition (see Table 3 below). Three readings were recorded for each material at each time point.

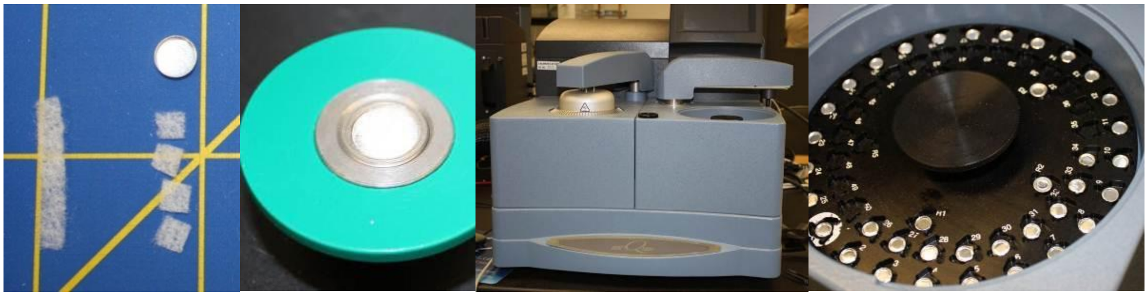


Figure 8: DSC preparation

Far left – cutting the sample into test pieces
Second to left – sample in the container (ready for the lid)
Second from right – Calorimeter
Far Right – samples capped and loaded for testing

DSC Test Method: (for actual values of MAX TEMP for each material see chart below)

1: Equilibrate at -90.00 °C

2: Ramp 20.00 °C/min to MAX TEMP °C

3: Mark end of cycle 0

4: Ramp 20.00 °C/min to -90.00 °C

5: Mark end of cycle 0

6: Ramp 20.00 °C/min to MAX TEMP °C

7: Mark end of cycle 0

Table 4: Test method maximum temperature chart for DSC

Material #s	**Composition**	**Type**	**Max DSC Temp**
1-3	PLLA	Film	220°C
4	PLLA	BIOFELT	220°C
5-7	PLA-PCL	Electrospun	200°C
8-13	PLA-PCL	Film	200°C
14-17	PLLA-PCL	Sponge	220°C
18	PGA	Warp Knit Mesh	260°C

Gel Permeation Chromatography (GPC)

After individual mass measurements were made with a digital scale, the samples for GPC were dissolved in the appropriate amount of chloroform to make a 1mg/ml solution. The samples were then agitated to completely dissolve the samples in the chloroform. The GPC samples were then run with 3 tests from each vial (3 tests for each material). Polystyrene standards were used to generate the calibration curve relating retention time to estimated molecular weight.

Scanning Electron Microscopy (SEM)

SEM photos were taken using a FEI 400 Scanning Electron Microscope on low vacuum setting with the voltage set to 5-10kV. The samples were placed on the SEM stage using carbon fiber tape. Initially the samples were viewed at low magnification (20-50x) to look for major signs of material breakdown. Images of significant features were recorded. At least one image of each material was recorded at 100x and at least 3 points were recorded at 400x.

Results

Initial Inspection and Qualitative Observation

pH observations: Most of the samples stayed within the desired pH range but many were close to a pH of 5 at the final measurement recorded as the samples were 'harvested.' Material 18 was particularly acidic and needed buffer solution several times to keep it within the desired pH range and went out of the desired range at the by the end of the last degradation period.

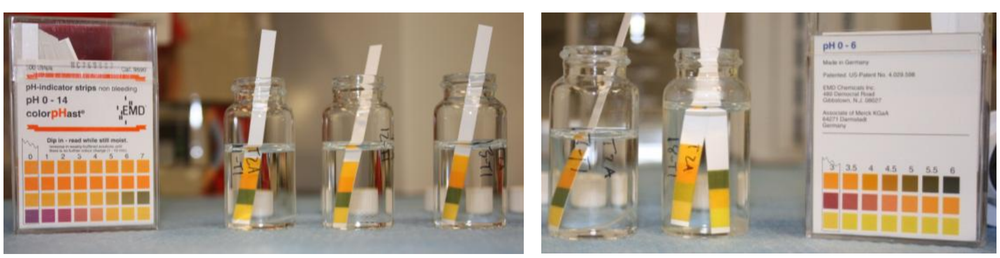


Figure 9: Select examples of 8 week pH testing – materials shown above from left to right 11, 12, 13, 17 and 18

Visual Inspection: All but the material 18 samples looked relatively similar to the initial samples to the unaided eye. The material 18 samples however, completely frayed into small fragments or fibers that were extremely difficult to collect. The fibers stuck to filter paper or were completely blown away by the slightest air current. Attempts to centrifuge the fibers from the solution also failed.

Percent mass lost

Upon initial inspection of the degradation data of all 18 materials, it appears compromised as a number of samples actually gained mass (a negative % mass lost on the graphic below) over time. It is hypothesized that due to time constraints of having ‘harvested’ a large quantity of samples at one time period, attempts to get them rinsed and dried in a short window of time may have allowed deposits from the buffer solution to remain on/in the samples due to incomplete rinsing. The possible incomplete rinsing issue was not apparent until after testing. Also, the PGA percent mass loss may be incorrectly high for the last few weeks as the material did not completely dissolve in the solution but much of it was suspended as fibers. These fibers could not be separated from the solution despite attempts to centrifuge them apart. PGA percent mass loss for the 8 week samples could not be measured at all because the fabric completely frayed.

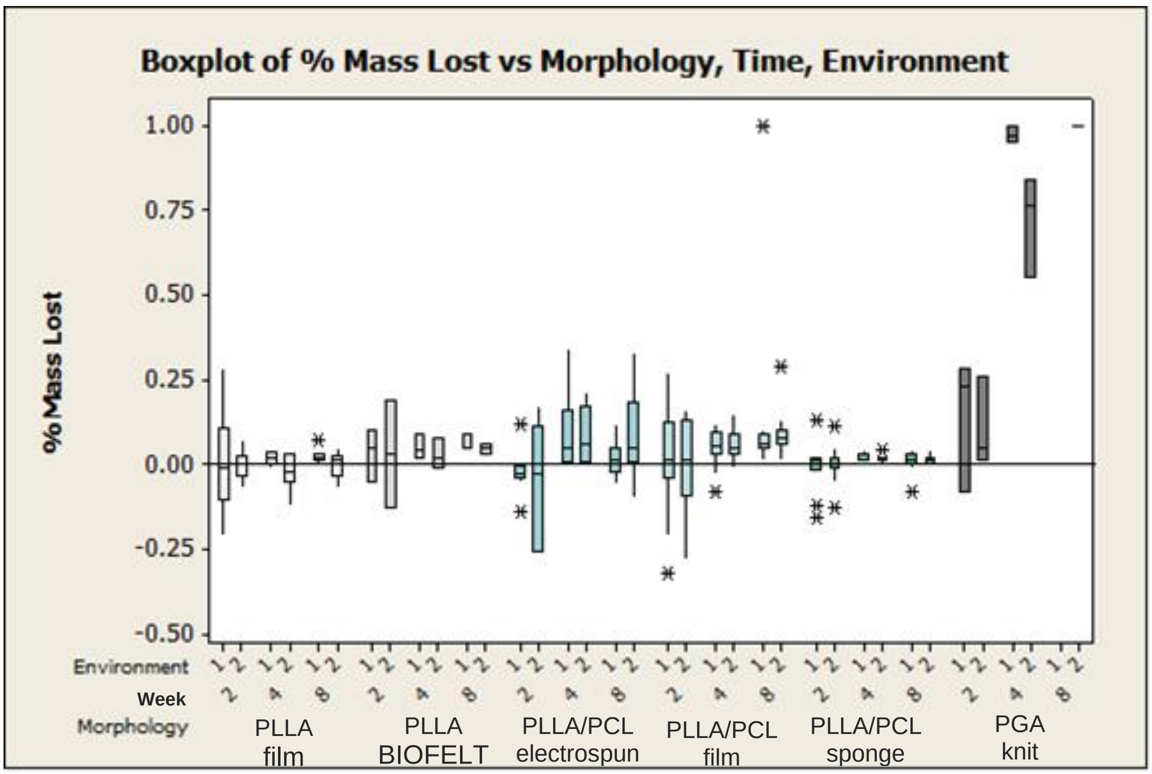


Figure 10: Boxplot of the percent mass lost for each material/morphology category vs. time and environment

Differential Scanning Calorimetry (DSC) Results

Table 5: Values of the average Tm at baseline in degrees C, note: materials 16 and 17 have no baseline data (graphs show baseline = 2wks stagnant data for material 16 and 17)

Average Tm at Baseline (degrees C)			
Material	Average	Material	Average
1-BL	176.98	14-BL	160.74
2-BL	176.49	15-BL	159.89
3-BL	176.79	16- 2 weeks*	158.97
4-BL	176.90	17- 2 weeks*	158.45
		18-BL	219.49

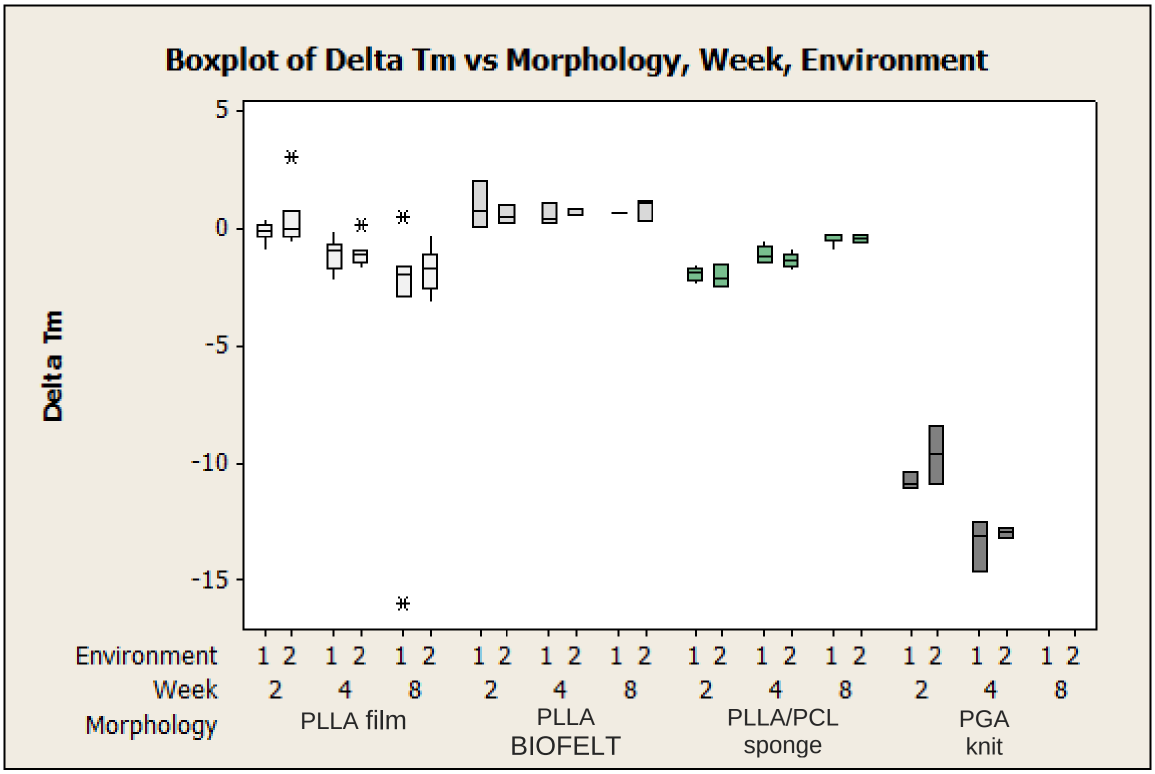


Figure 11: Boxplot of change in Tm from baseline in degrees C, plotted by morphology (material group) with materials 16 and 17 removed

Table 6: Average Tg values at baseline (degrees C)

Average Tg at Baseline (degrees C)			
Material	Average	Material	Average
1-BL	59.50	10-BL	18.81
2-BL	58.86	11-BL	19.34
3-BL	59.41	12-BL	20.32
4-BL	60.31	13-BL	18.96
5-BL	19.52	14-BL	38.65
6-BL	20.09	15-BL	37.90
7-BL	20.10	16- 2 weeks*	27.30
8-BL	19.40	17- 2 weeks*	33.40
9-BL	21.08	18-BL	38.45

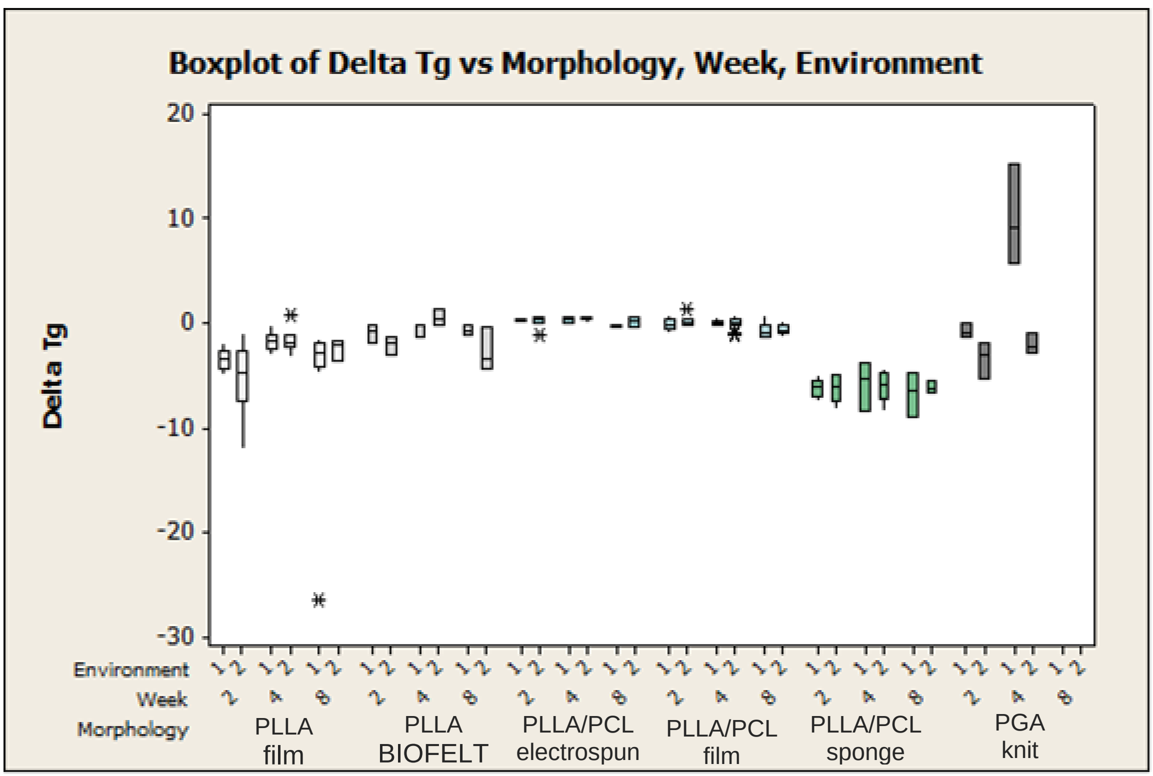


Figure 12: Boxplot of change in Tg from baseline in degrees C, plotted by morphology (material group) with materials 16 and 17 removed

Table 7: Average Tc values at baseline (degrees C) *values reported here for baseline 16, 17 and 18 are from the 2 week data

Average Tc at Baseline (degrees C)			
Material	Average	Material	Average
1-BL	133.09	15-BL	120.97
2-BL	123.96	16- 2 weeks*	125.22
3-BL	132.20	17- 2 weeks*	124.58
4-BL	108.26	18- 2 weeks*	101.38
14-BL	125.21		

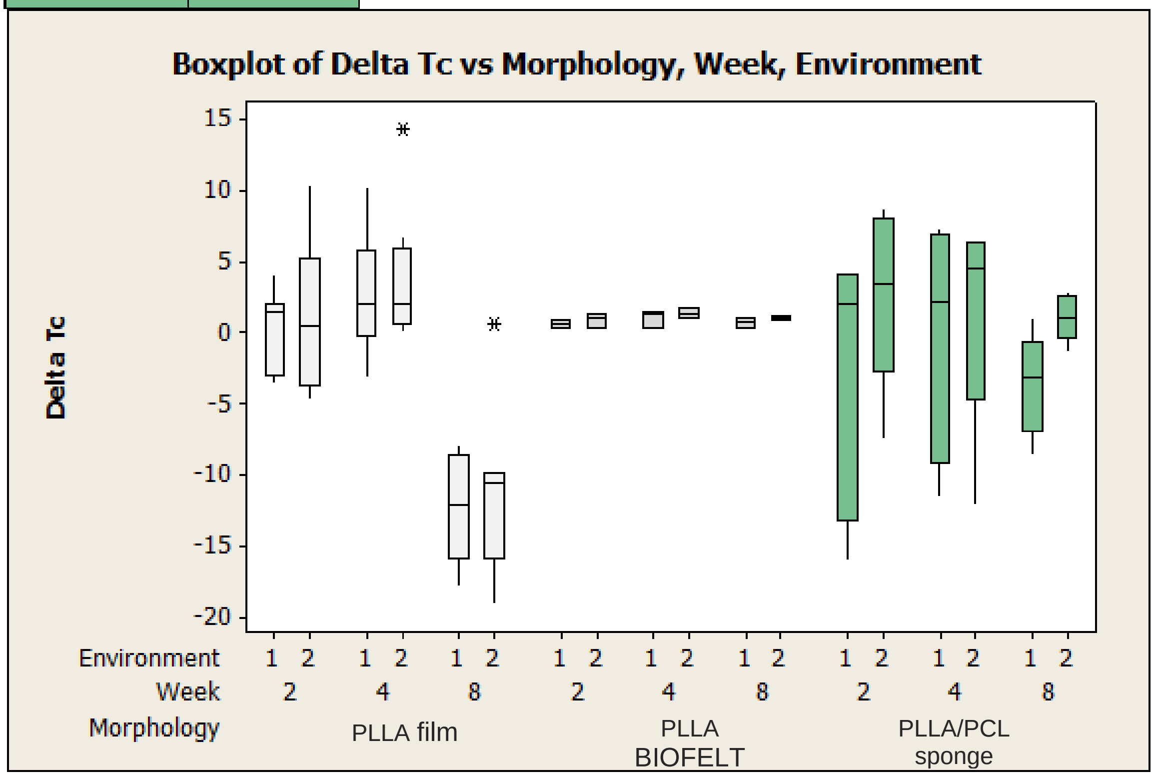


Figure 13: Boxplot of change in Tc from baseline in degrees C, plotted by morphology (material group) *Note that materials 16, 17 and 18 are not plotted due to missing baseline values

No statistical analysis was performed on DSC data because not every set of sample groups contains three measures due to equipment error. Results for melting temperature (Tm) suggest slight change over time but no material changed more than 10% from the corresponding baseline measures. With the exception of a couple of measures, the glass transition temperature (Tg) remained within 10% of baseline except for materials 14 and

15 which appear to hover around 20% of baseline and the 4 weeks stagnant group of material 18 which increased 20-40%. The crystallization temperature (Tc) of the materials suggest slight change over time, particularly the PLLA film materials between 4 and 8 weeks, but no material was more than 15% different from baseline measures.

Scanning Electron Microscopy (SEM) Results

Overall, there was not any major damage (fractures/cracks/etc.) recorded in the scanning electron microscopy images (with the exception of material 18). The following is a selection of representative images at 100x and 400x magnification of each of the 18 materials at baseline and at 8 weeks agitated (except for material 18 which is baseline and 4 weeks agitated).

Table 8: Notable SEM results

PLLA materials 1 through 3 had no visible changes
The fibers of the PLLA BIOFELT appeared to swell and slightly spread out at 8 weeks degradation.
The fibers of the electrospun PLLA/PCL materials 5, 6 and 7 appeared to spread slightly by 8 weeks degradation.
The surface of the PLLA/PCL films (materials 8 through 13) appears rougher at 8 weeks degradation.
Materials 14 through 17, the PLLA/PCL sponges all appear rougher at 8 weeks degradation and small, concentrated pockets of material appear to be missing on material 14.
PGA material 18 completely unraveled by 8 weeks. At 4 weeks the distinct knit pattern was almost completely disrupted.

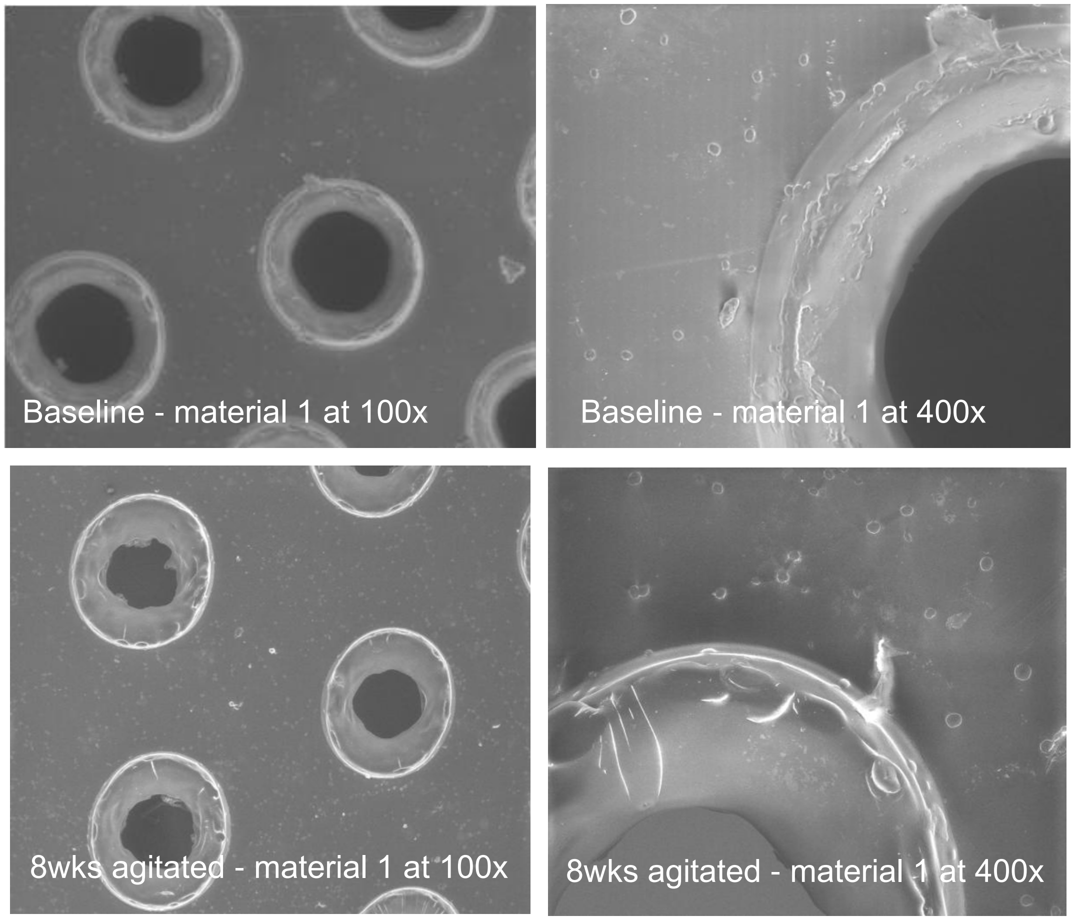


Figure 14: Baseline and 8 weeks agitated SEM images for PLLA film material 1 magnified 100 and 400 times

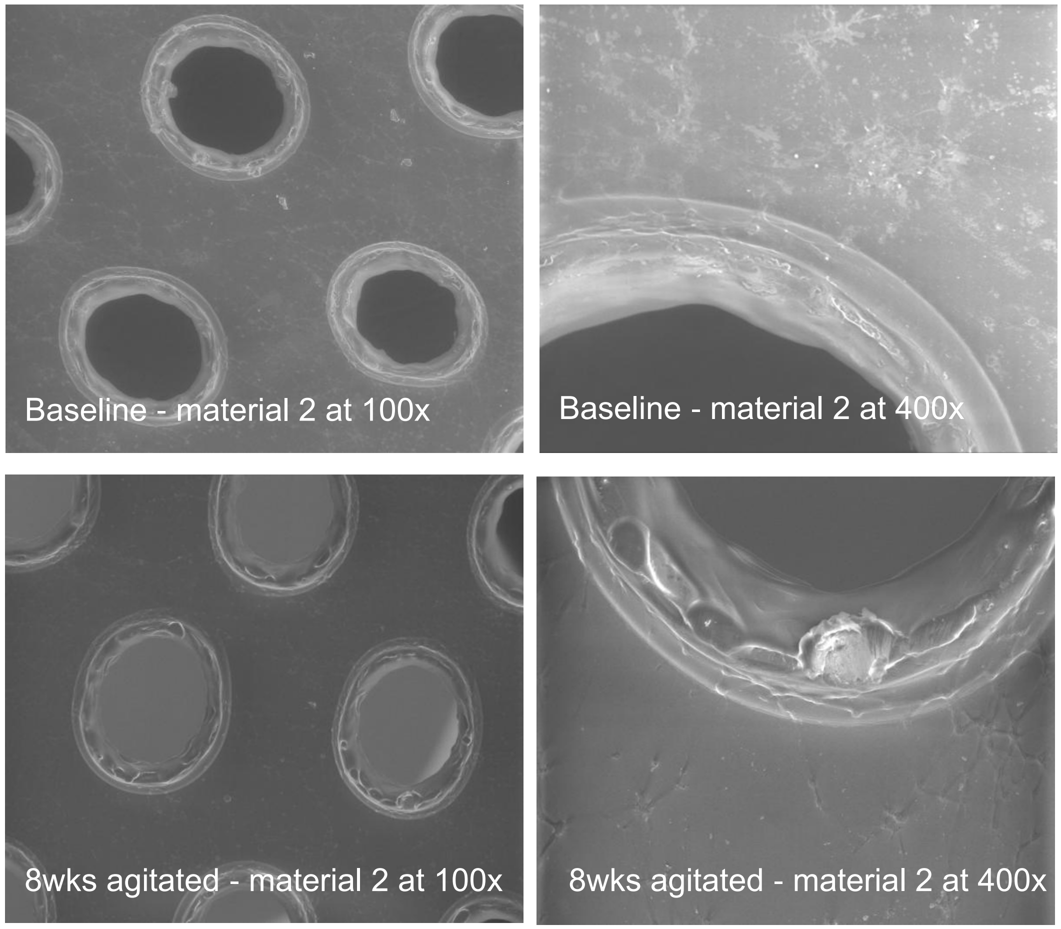


Figure 15: Baseline and 8 weeks agitated SEM images for PLLA film material 2 magnified 100 and 400 times

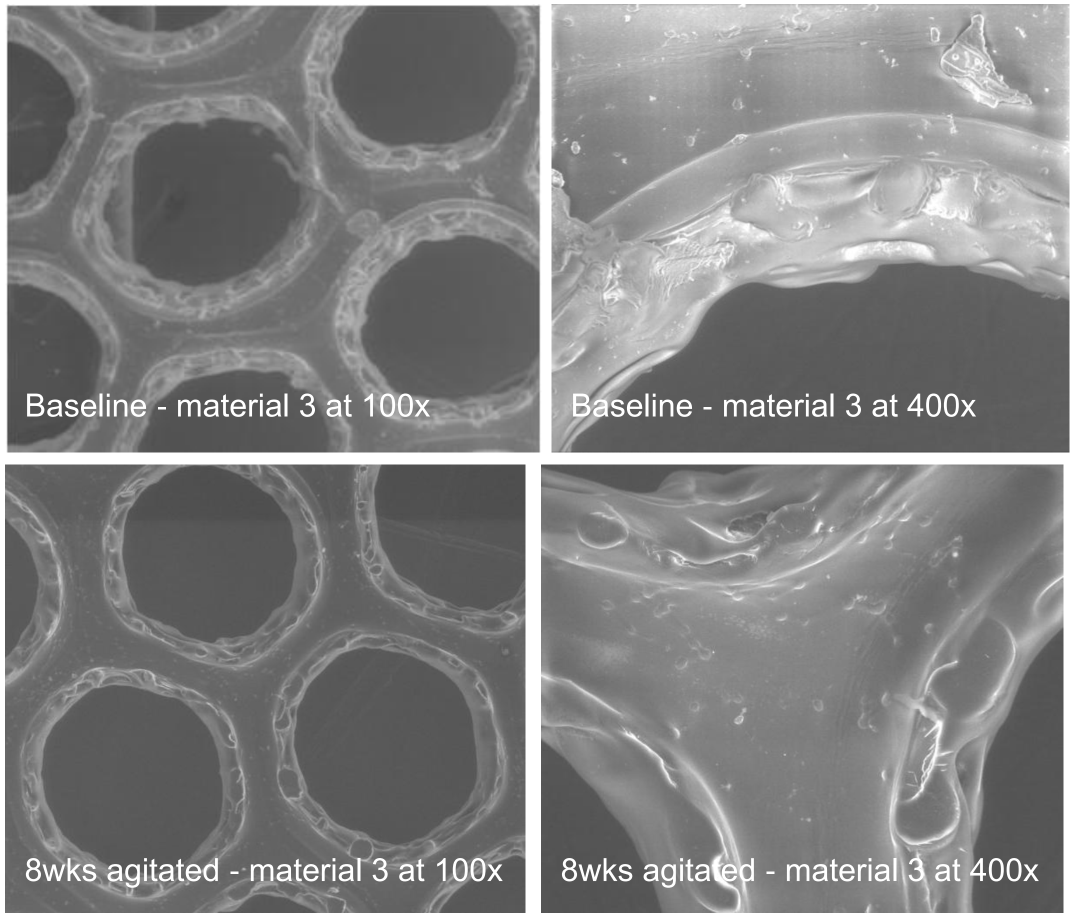


Figure 16: Baseline and 8 weeks agitated SEM images for PLLA film material 3 magnified 100 and 400 times

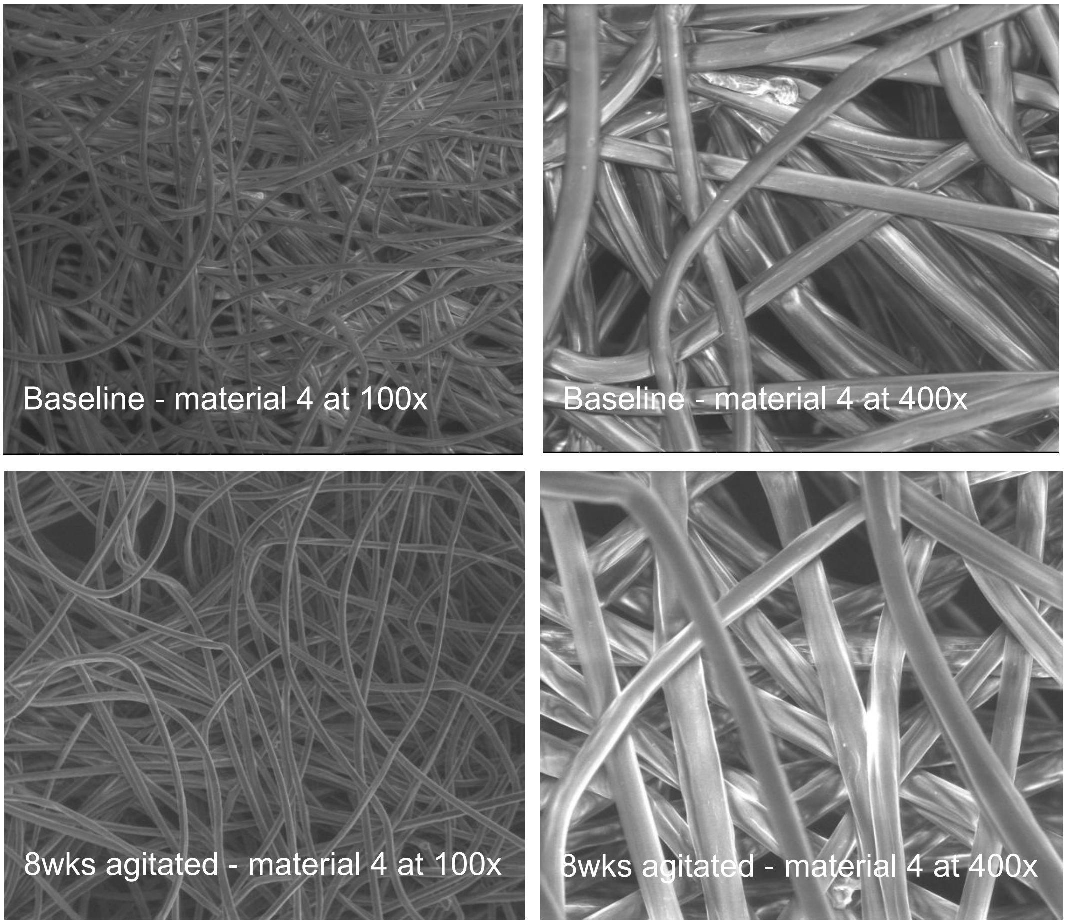


Figure 17: Baseline and 8 weeks agitated SEM images for PLLA BIOFELT material 4 magnified 100 and 400 times

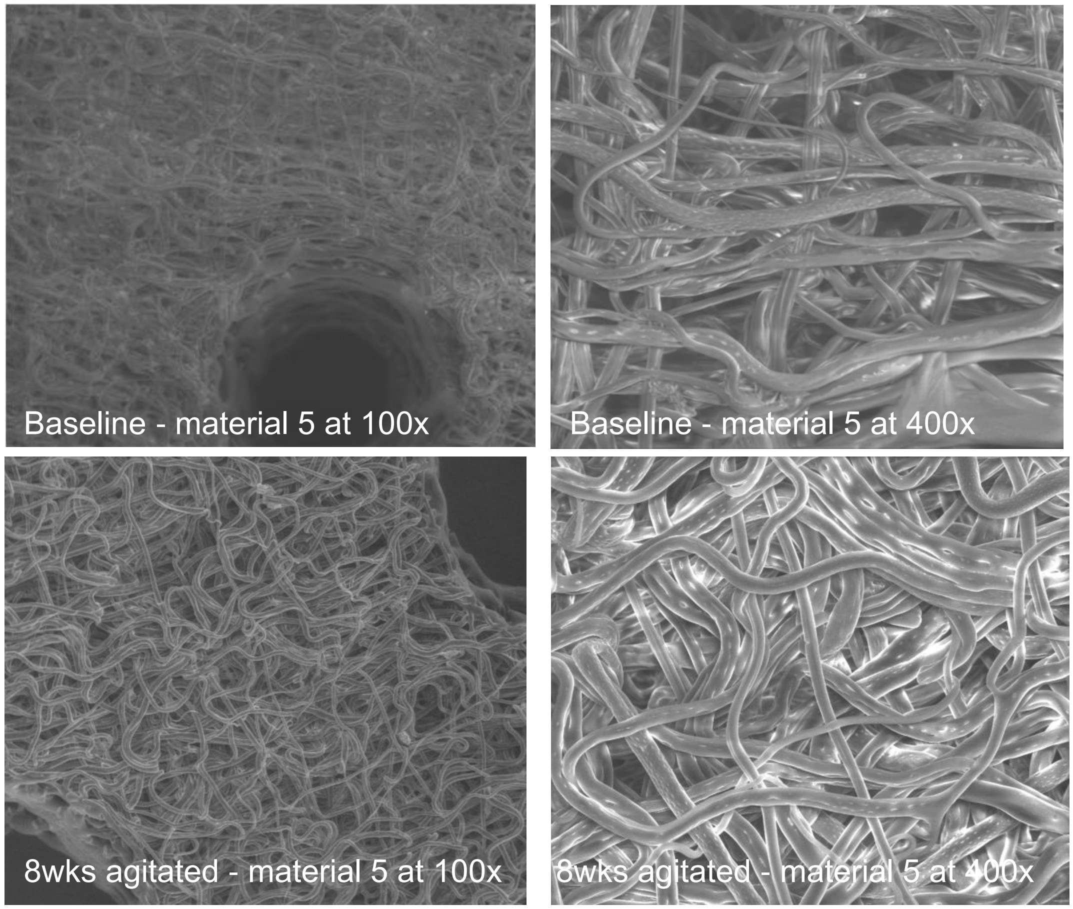


Figure 18: Baseline and 8 weeks agitated SEM images for PLLA/PCL electrospun material 5 magnified 100 and 400 times

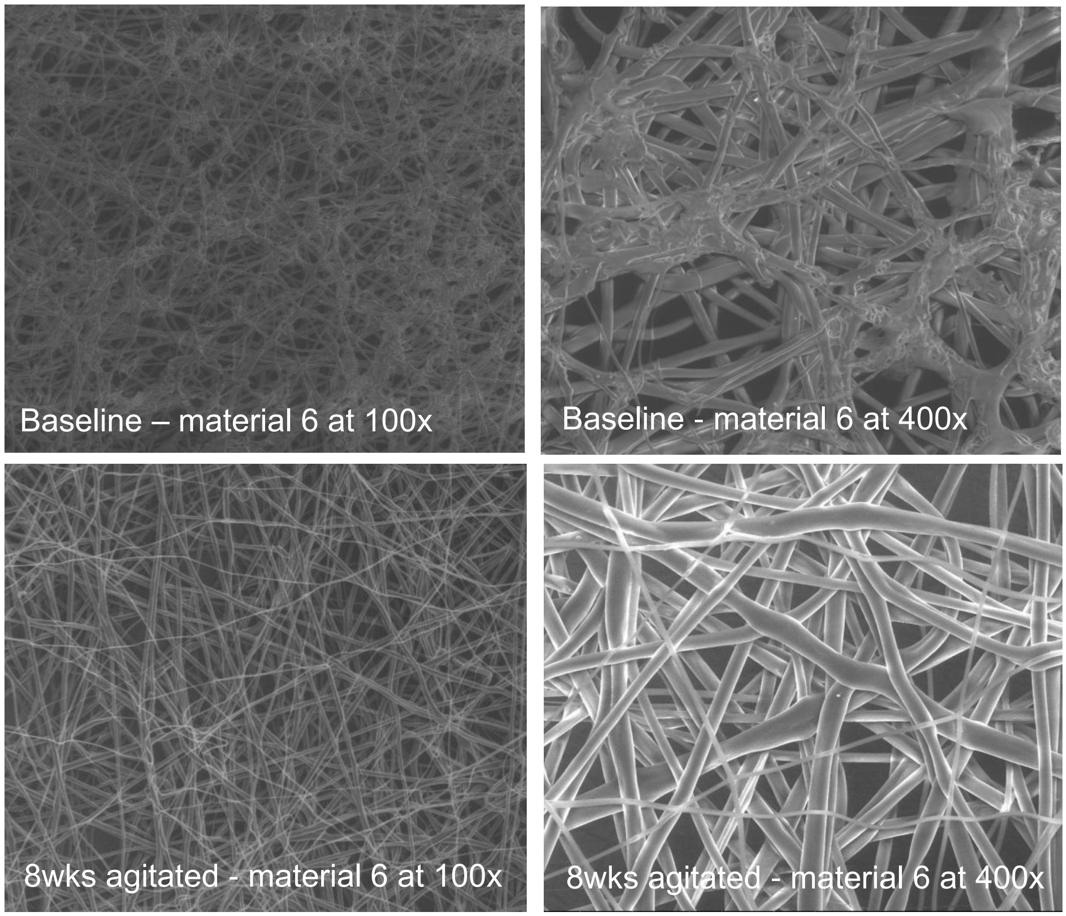


Figure 19: Baseline and 8 weeks agitated SEM images for PLLA/PCL electrospun material 6 magnified 100 and 400 times

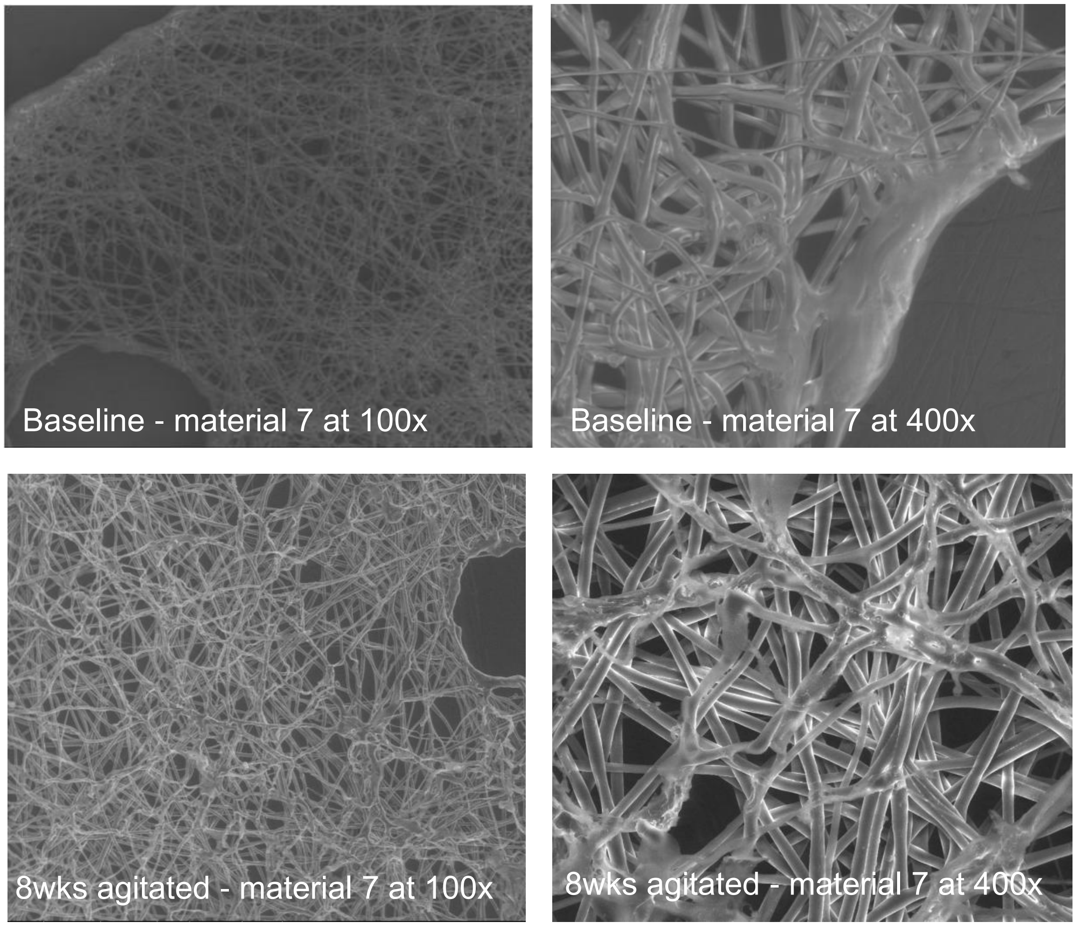


Figure 20: Baseline and 8 weeks agitated SEM images for PLLA/PCL electrospun material 7 magnified 100 and 400 times

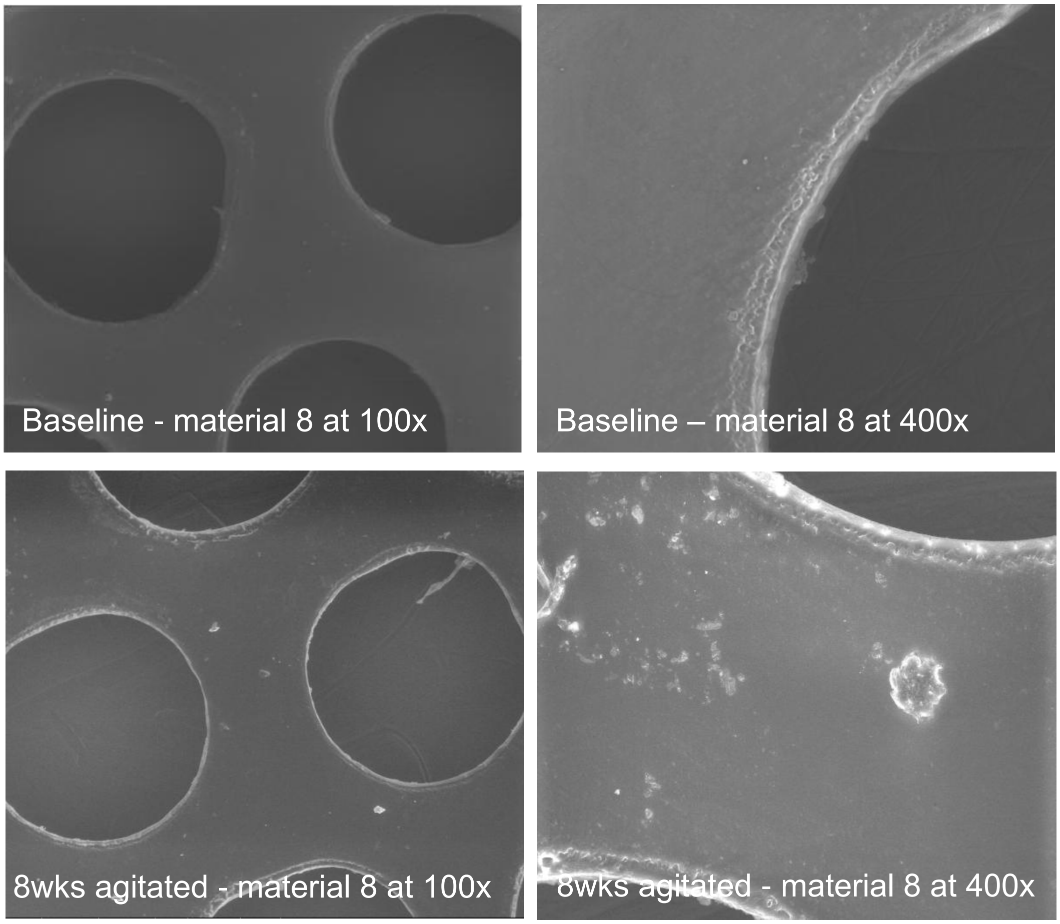


Figure 21: Baseline and 8 weeks agitated SEM images for PLLA/PCL film material 8 magnified 100 and 400 times

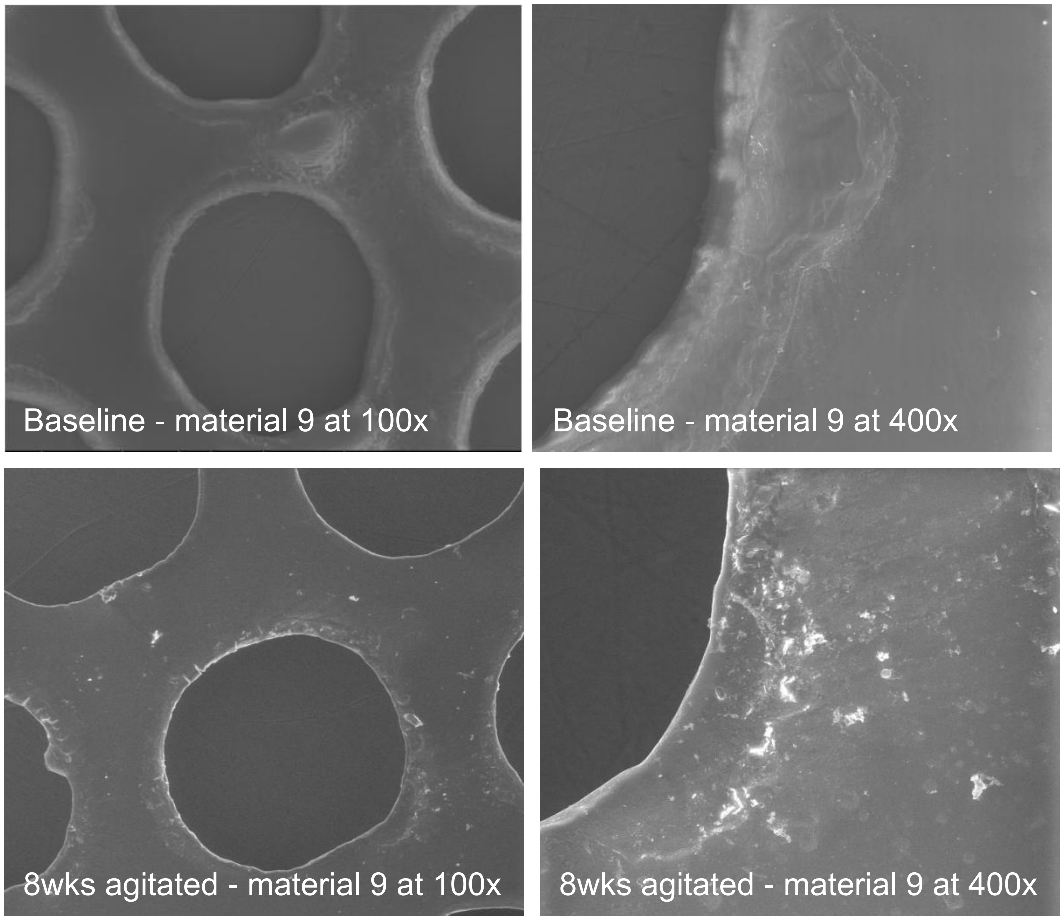


Figure 22: Baseline and 8 weeks agitated SEM images for PLLA/PCL film material 9 magnified 100 and 400 times

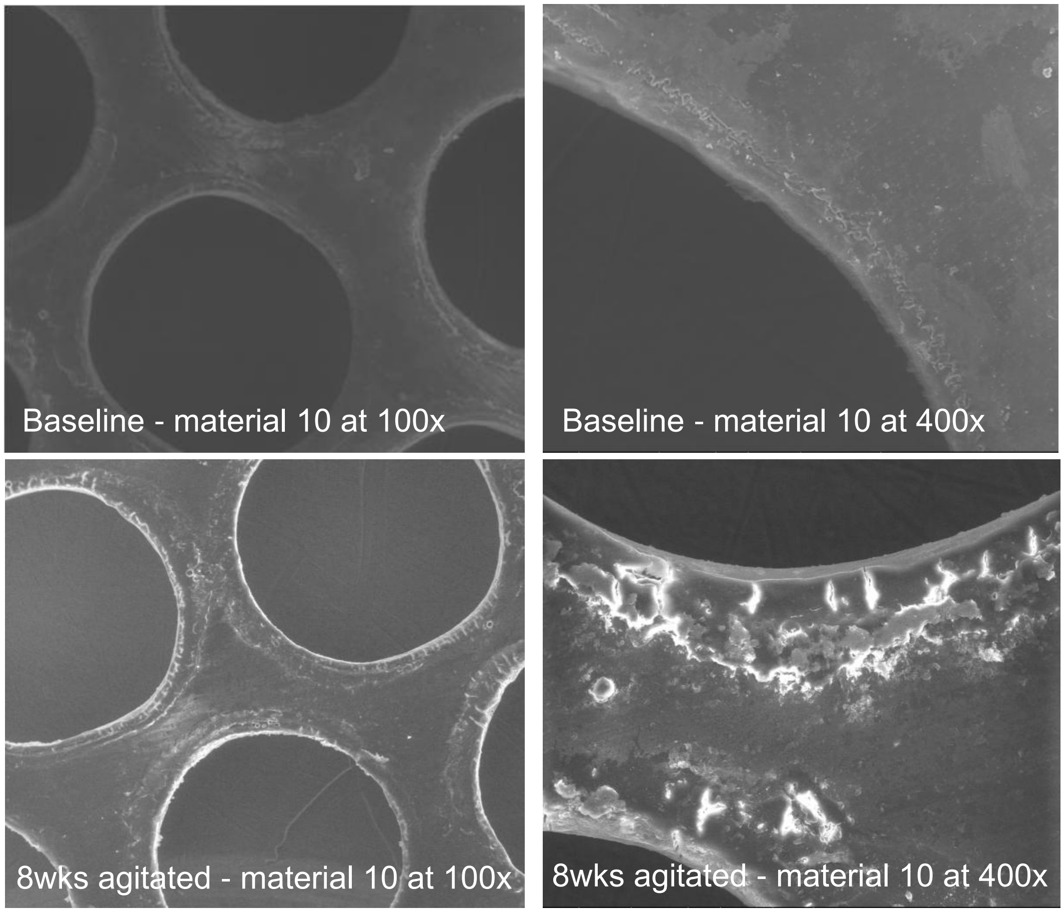


Figure 23: Baseline and 8 weeks agitated SEM images for PLLA/PCL film material 10 magnified 100 and 400 times

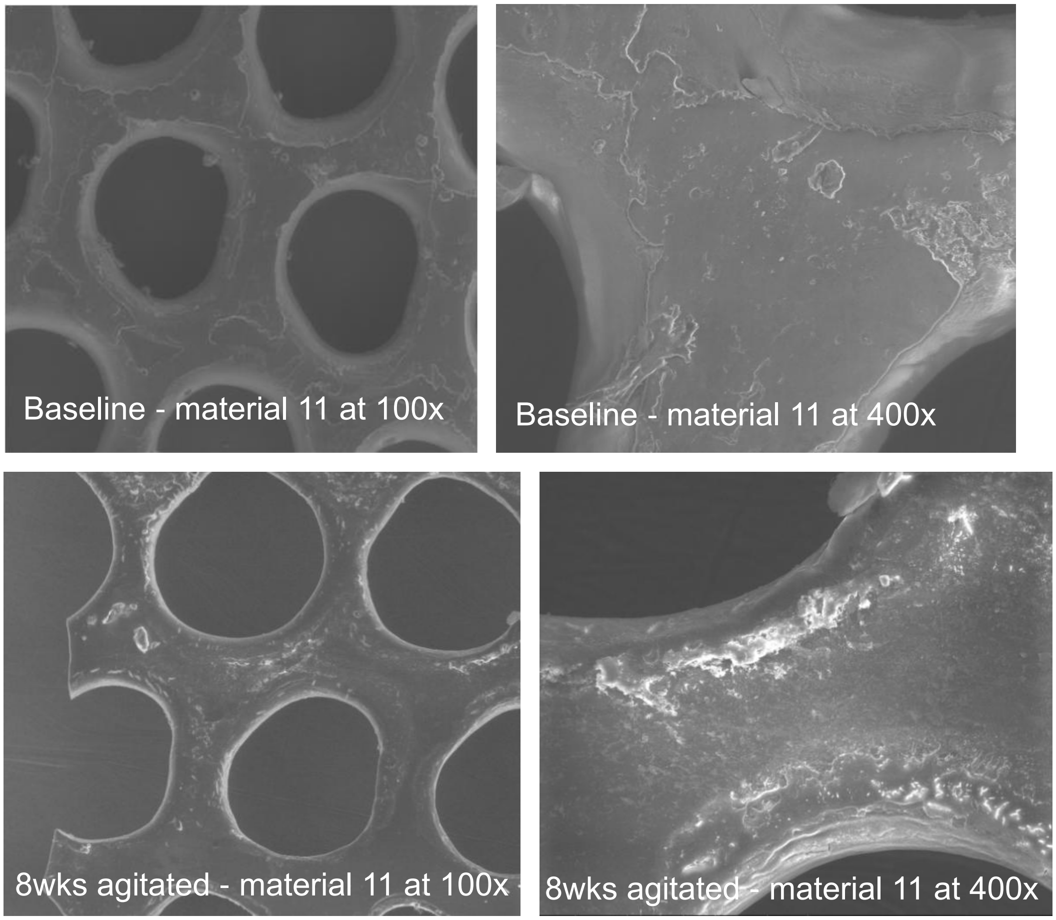


Figure 24: Baseline and 8 weeks agitated SEM images for PLLA/PCL film material 11 magnified 100 and 400 times

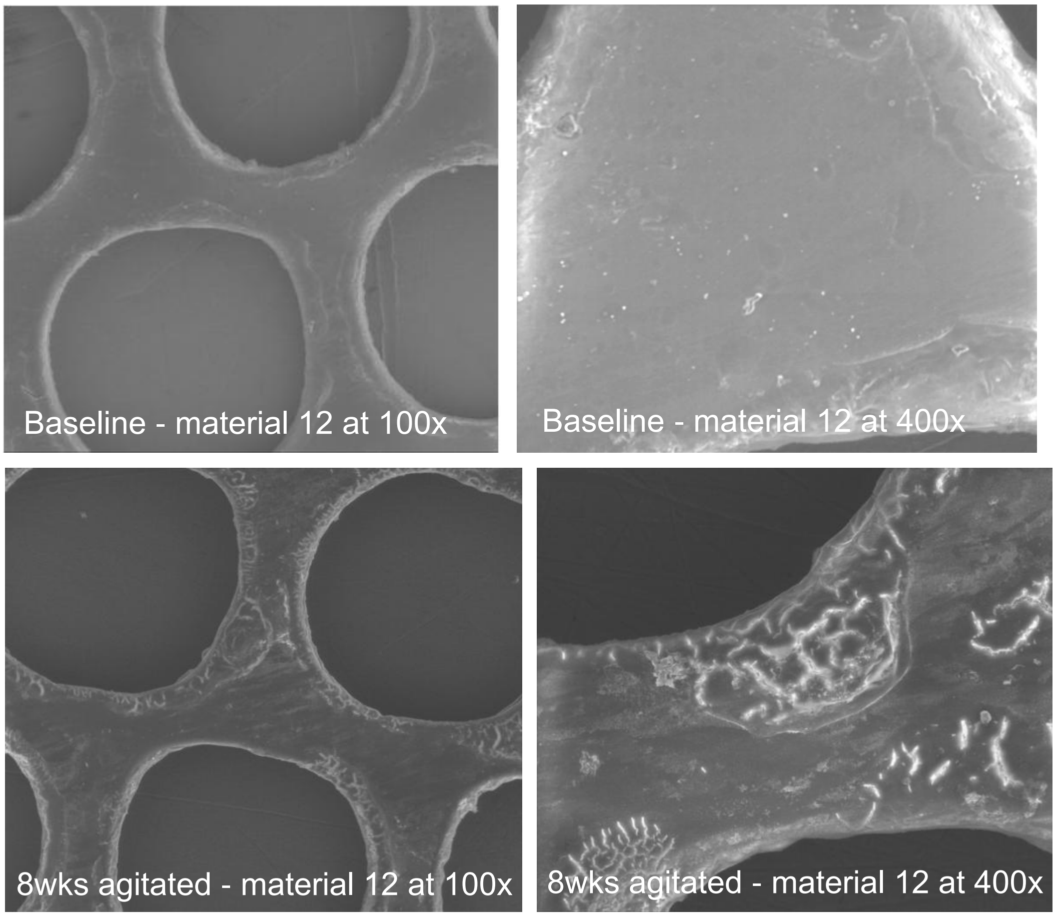


Figure 25: Baseline and 8 weeks agitated SEM images for PLLA/PCL film material 12 magnified 100 and 400 times

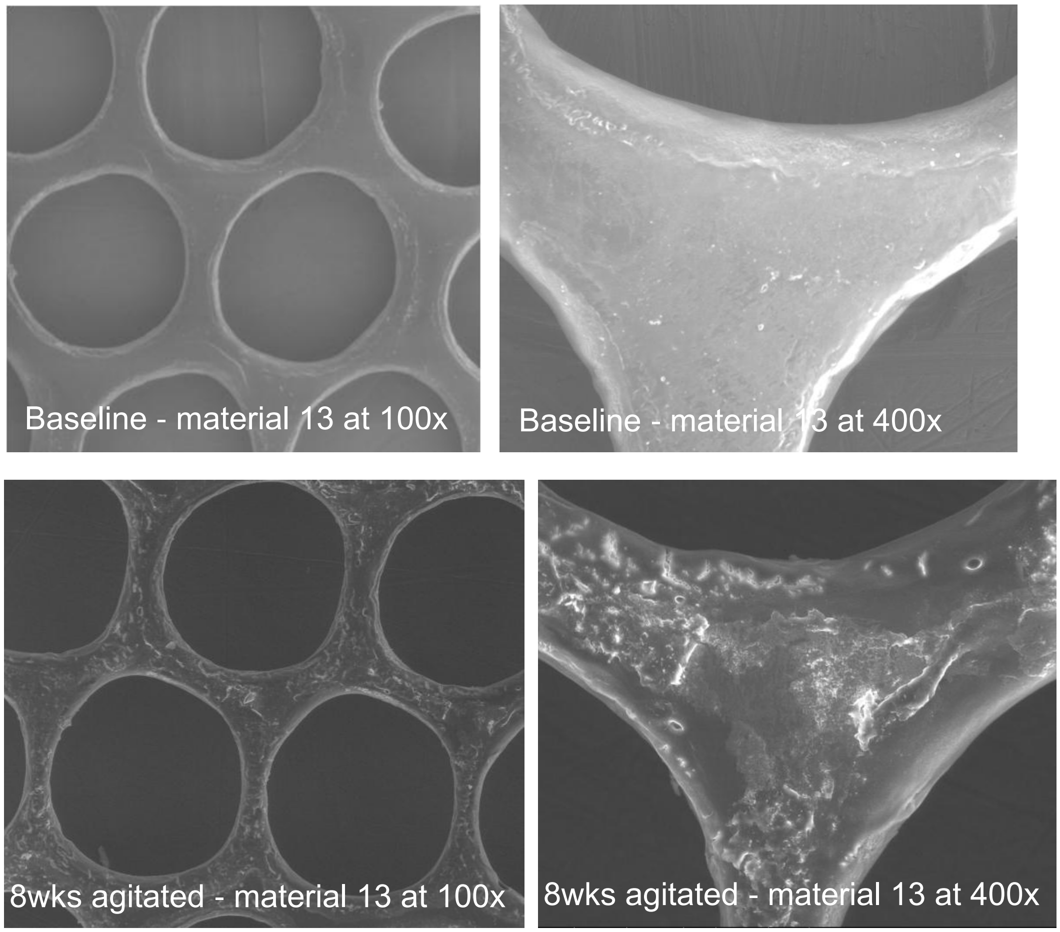


Figure 26: Baseline and 8 weeks agitated SEM images for PLLA/PCL film material 13 magnified 100 and 400 times

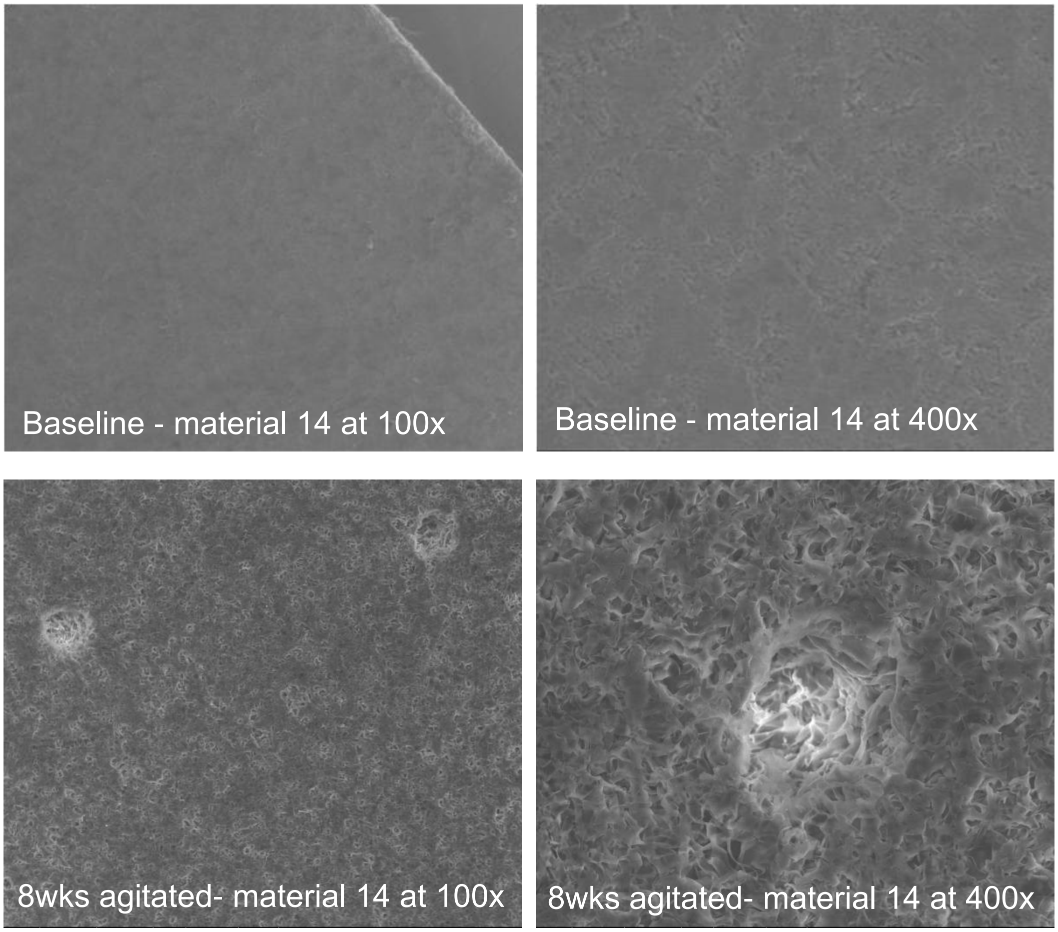


Figure 27: Baseline and 8 weeks agitated SEM images for PLLA/PCL sponge material 14 magnified 100 and 400 times

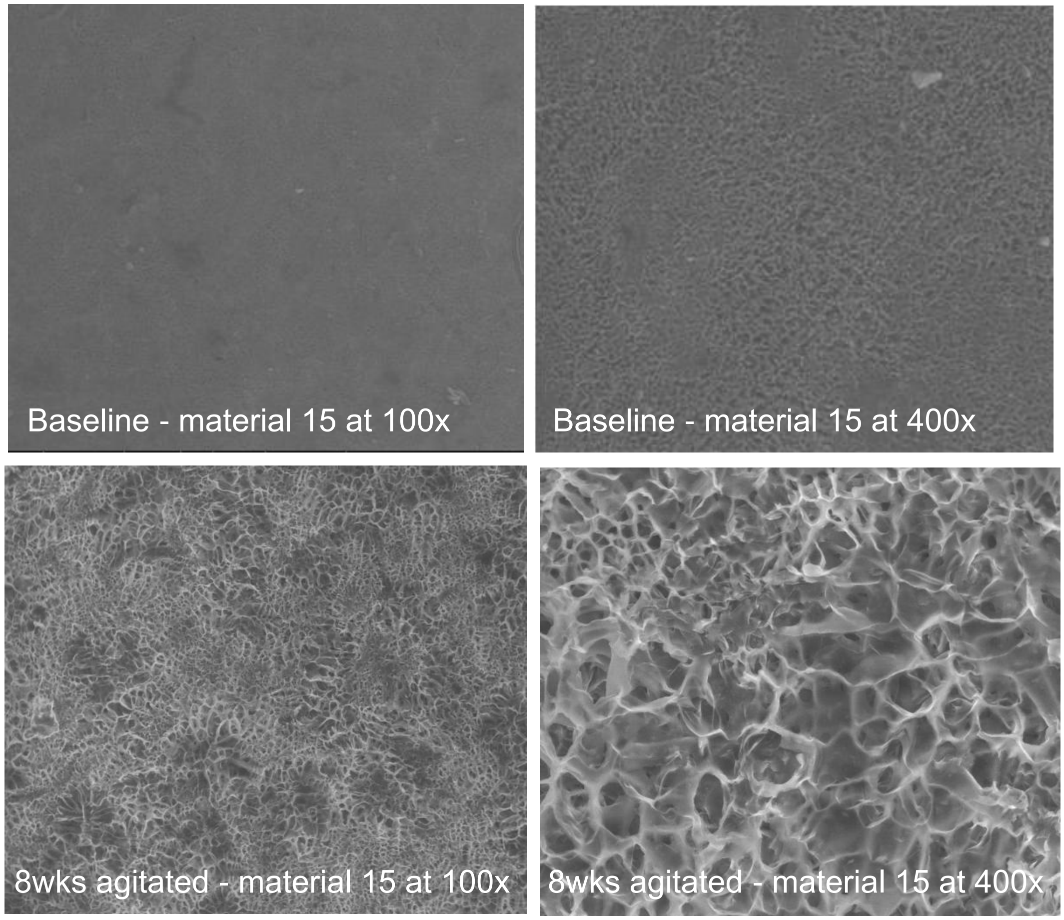


Figure 28: Baseline and 8 weeks agitated SEM images for PLLA/PCL sponge material 15 magnified 100 and 400 times

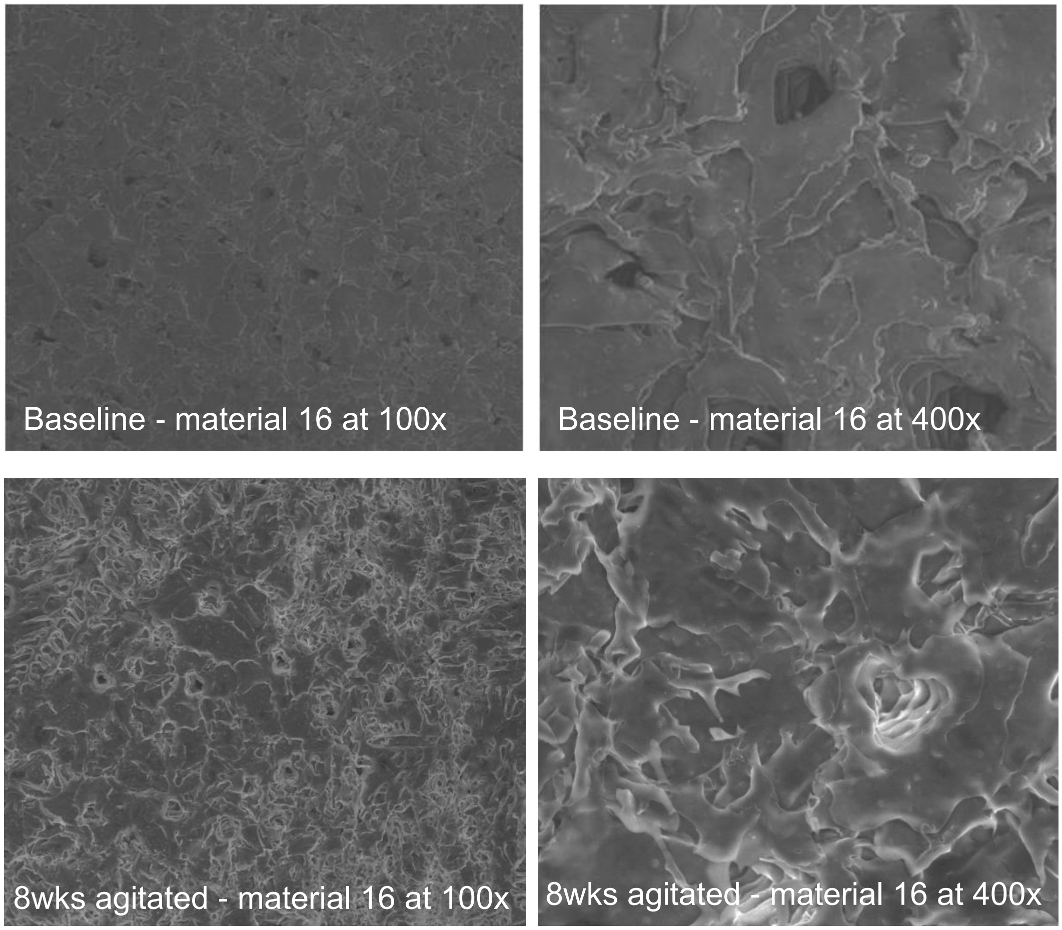


Figure 29: Baseline and 8 weeks agitated SEM images for PLLA/PCL sponge material 16 magnified 100 and 400 times

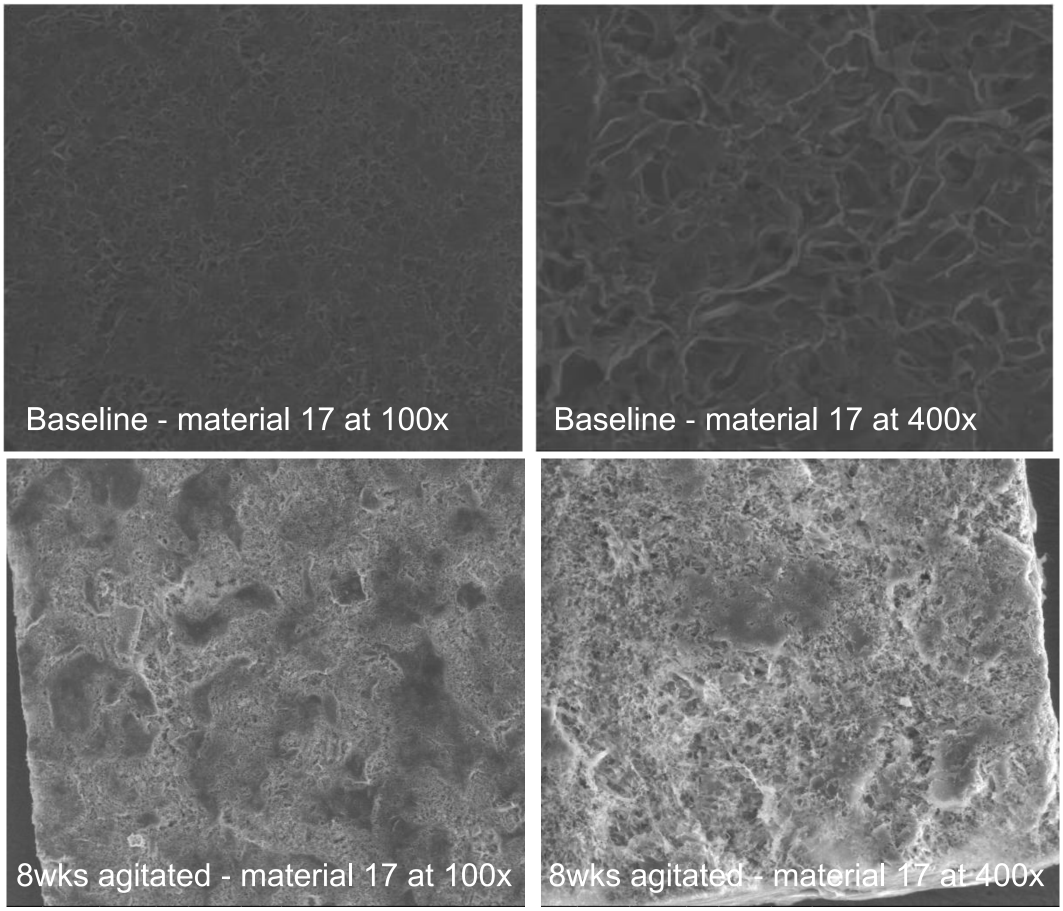


Figure 30: Baseline and 8 weeks agitated SEM images for PLLA/PCL sponge material 17 magnified 100 and 400 times

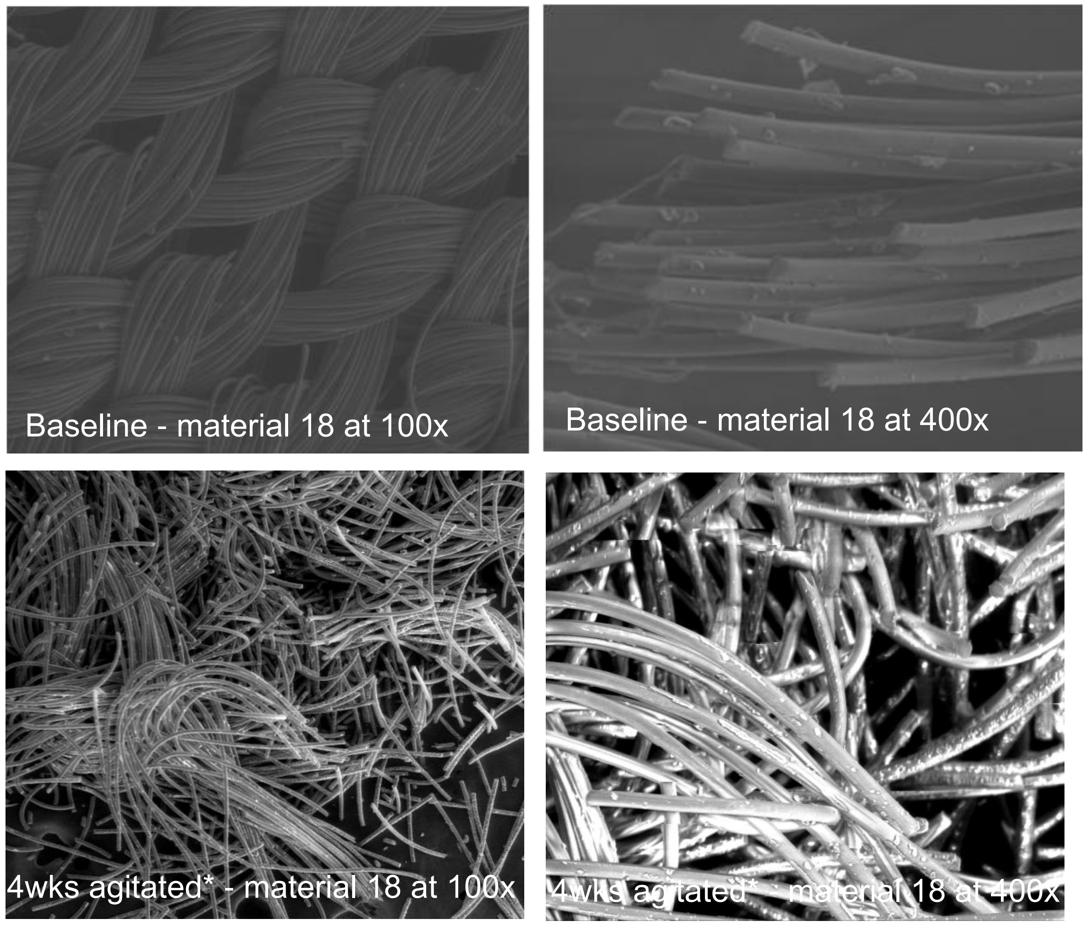


Figure 31: Baseline and 4 weeks agitated SEM images for PGA knit material 18 magnified 100 and 400 times

Gel Permeation Chromatography (GPC) Results and Analysis

Table 9: The average molecular weights of material samples (average of 3 samples) at baseline

Average Molecular Weight at Baseline (Daltons)			
Material	Average	Material	Average
1-BL	488452	10-BL	186032
2-BL	478550	11-BL	187238
3-BL	441904	12-BL	303532
4-BL	137012	13-BL	176727
5-BL	212149	14-BL	185358
6-BL	225717	15-BL	182455
7-BL	222509	16-BL	159383
8-BL	191354	17-BL	185225
9-BL	327606		

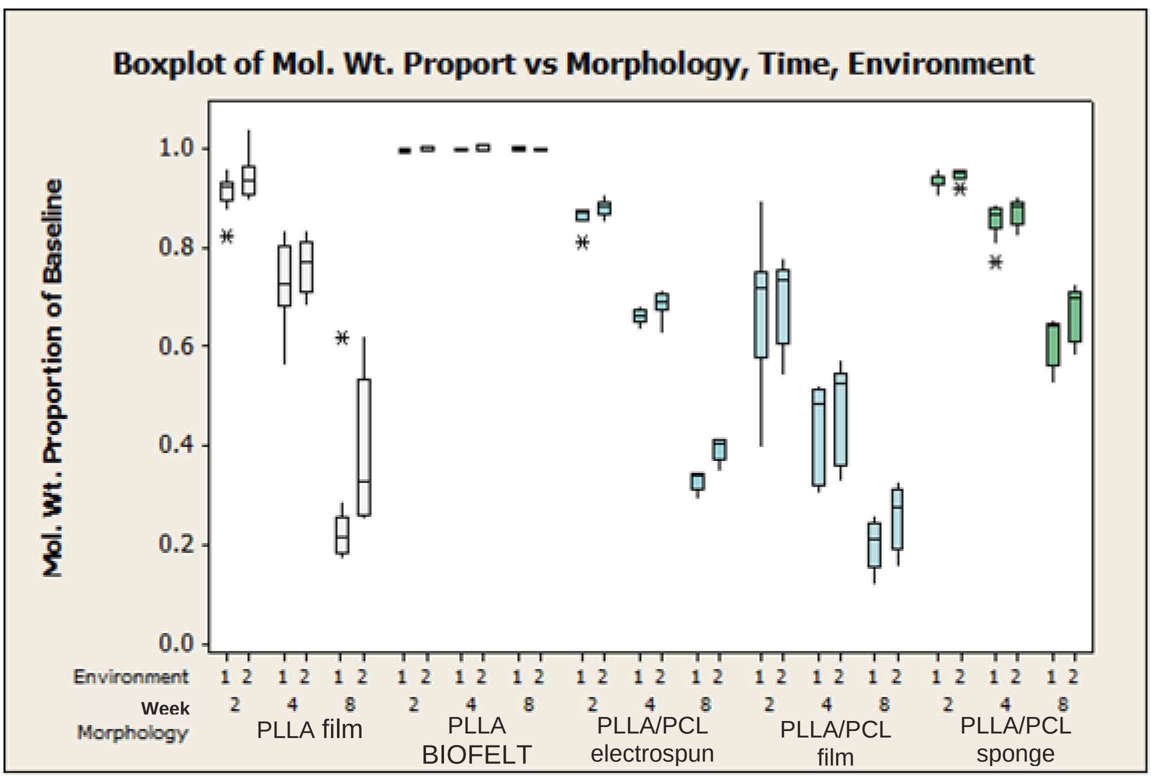


Figure 32: Boxplot of the proportion of the molecular weight at baseline by morphology, degradation time and degradation environment

GPC Data Analysis

There are several main effects as well as several interactions found in the proportional molecular weight data (see Appendix II for molecular weight Minitab ANOVA output). An initial three-way (Material x Degradation Time x Degradation Environment, n = 3) analysis of variance (ANOVA) demonstrated that all main effects and interactions were statistically significant ($p < 0.01$). The significance of the factor of material is expected as there were two separate chemical composition groups included in this ANOVA. The significance of the factor of time suggests that the molecular weight of the materials changed over time. Referencing Figure 13 it is clear that for all materials except material 4 there was a decrease in molecular weight, or degradation, at the time periods measured in this study (0-8 weeks). Also, it appears the degradation environment also generated significantly different measures of molecular weight which suggests possible differences in degradation in a stagnant vs. agitated environment. The significance of the interactions suggests that the molecular weights of each material changed differently with time and that the degradation environment affected the change in molecular weight of different materials with different magnitudes.

To investigate how each material's individual morphology (felt, electrospun, film, sponge and porosity/density) affected degradation a second set of three-way ANOVAs (n = 3) were performed for each chemical composition group (the PLLAs and the PLLA/PCLs). Interaction plots of the two data sets supported including all main effects and two factor interactions. Again, all main effects and interactions were significant ($p < 0.01$) with three exceptions. For all materials (both ANOVAs) the material-with-environment interaction was not significant and the environment-with-time interaction of materials 1 through 4 was also not significant. This would suggest that the material-environment interaction only occurs between the two material composition groups (PLLAs vs. PLLA/PCLs) and not within them. The significance of the factor of material for both data sets now demonstrates that the individual properties of the 17 materials has a statistically significant effect on molecular weight changes and the interaction of material and degradation time also support a statistically significant difference in rate of change of molecular weight for the different materials. Once again, the degradation environment factor was also statistically significant suggesting differences in molecular weight related to the degradation environment.

Tensile Testing: Peak Strain Results and Analysis

Table 10: Values of the average peak strain for each of the materials at baseline (Mpa)

Average Peak Strain at Baseline (Mpa)			
Material	Average	Material	Average
1-BL	11.99	10-BL	677.48
2-BL	21.18	11-BL	548.69
3-BL	17.70	12-BL	644.91
4-BL	49.43	13-BL	476.69
5-BL	291.16	14-BL	32.97
6-BL	436.90	15-BL	71.72
7-BL	361.85	16-BL	80.83
8-BL	698.65	17-BL	24.85
9-BL	453.73	18-BL	452.22

For the peak strain analysis the values for material 18 are removed due to the fact that the material completely unraveled, making tensile testing impossible, after only two weeks.

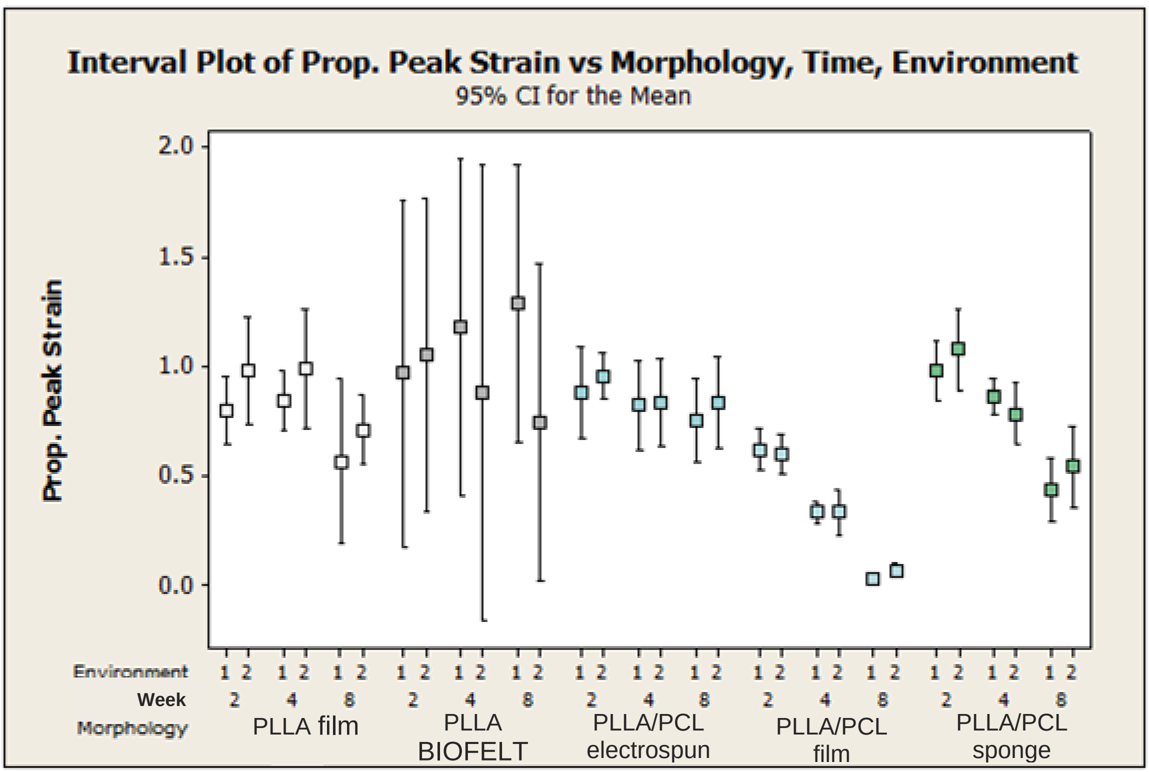


Figure 33: Interval plot of the peak strain proportion of baseline peak strain

Peak Strain Analysis

For statistical analysis of the peak strain data, a complete data set with replicates of 3 had to be produced from the mean and standard deviation for each material at each time point as a complete raw data set was not available.

An interaction plot of the proportion of peak strain from baseline by material, degradation time and degradation environment demonstrated that main effects and two factor interactions were present so these were all included in a 3-way ANOVA (n = 3) of the proportional strain (see Appendix III for proportional peak strain Minitab output). Only the main effect of the degradation environment and the interaction of degradation time and environment were not significant. This is interesting in that it suggests that although the molecular weight change was statistically different depending on the environment the difference was not great enough to generate a statistically significant change in the mechanical property of peak strain for these materials at the time points measured.

Further ANOVAs (n = 3) performed on the two chemical composition groups confirm that the effect of degradation environment was not significant for either set of materials. In addition, the effect of degradation time was not statistically significant for the PLLA group suggesting that the degradation of these materials was not sufficient to affect the peak strain behavior of these materials. This is not the case for the PLLA/PCL group where both main effects of material and degradation time as well as the material-time interaction were all significant ($p < 0.01$) indicating differences between materials, differences with increasing degradation time and different rates of behavior change over time for the different PLLA/PCL materials.

To further understand the degradation over time of individual materials one-way ANOVAs for each individual material (excluding material 18) by time were performed As the factor of degradation environment was not significant, the data for each material in each environment were combined (n=6). PLLA materials 3 and 4 as well as

PLLA/PCL materials 5, 6, 7 and 17 were not significantly different ($p > 0.01$) up to the last point measured, 8 week degradation period. This would suggest that would indicate that degradation over 8 weeks did not significantly affect the strain behavior of these materials.

Table 11: Results of one-way ANOVAs of proportional peak strain by degradation time (Note: x means the difference between Tukey 95% confidence intervals included zero)

Results of One-way ANOVAs of Proportional Peak Strain by Degradation Time				
Material	p-value	2 weeks vs. 4 weeks	2 weeks vs. 8 weeks	4 weeks vs. 8 weeks
1	0.002			x
2	0.001	x		
3	0.107	x	x	x
4	0.995	x	x	x
5	0.969	x	x	x
6	0.151	x	x	x
7	0.038	x		x
8	0.000			
9	0.000			
10	0.000			
11	0.000			
12	0.000			
13	0.000			x
14	0.000			
15	0.000			
16	0.000	x		
17	0.021	x		x

Tensile Testing: Peak Stress Results and Analysis

Table 12: Values of the average peak stress at baseline (Mpa)

Average Peak Stress at Baseline (Mpa)			
Material	Average	Material	Average
1-BL	15.34	10-BL	6.87
2-BL	24.00	11-BL	6.61
3-BL	13.74	12-BL	5.86
4-BL	0.10	13-BL	3.24
5-BL	1.79	14-BL	2.23
6-BL	6.25	15-BL	1.43
7-BL	3.37	16-BL	3.34
8-BL	9.50	17-BL	0.70
9-BL	6.00	18-BL	18.67

For the peak stress analysis the values for material 18 are removed due to the fact that the material became completely unraveled, making tensile testing impossible, after only two weeks.

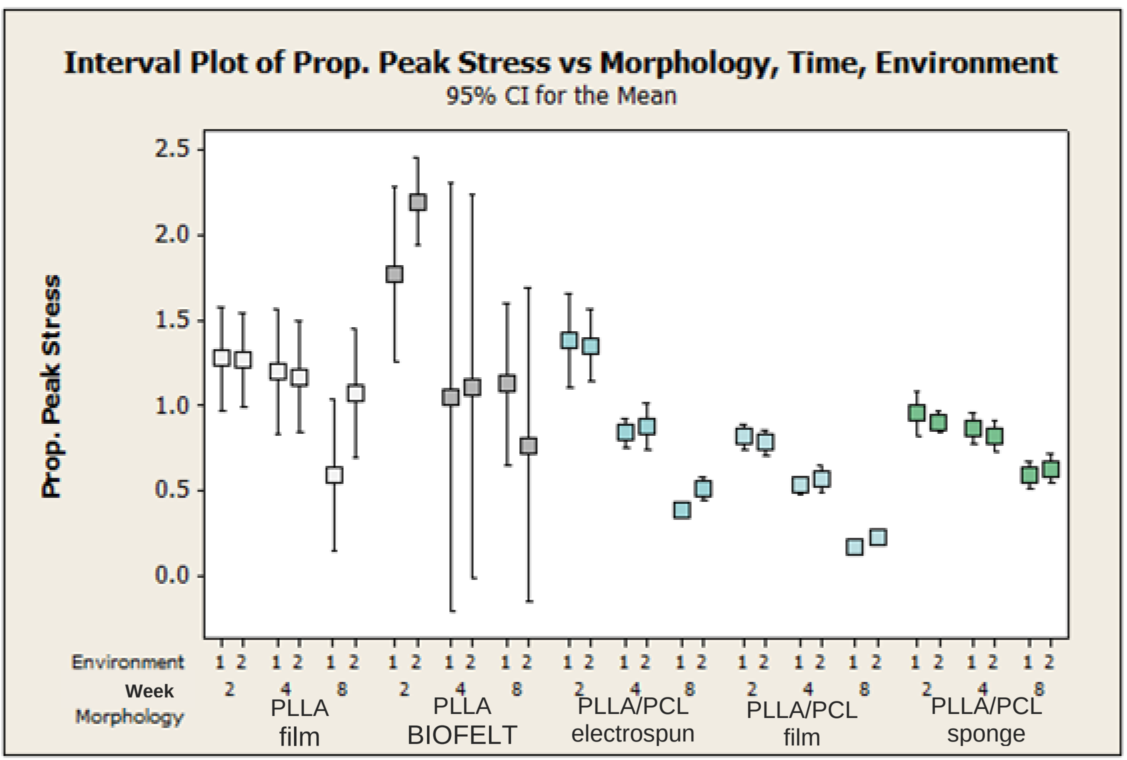


Figure 34: Interval plot of the peak stress proportion of baseline peak stress

Peak Stress Analysis

As with strain, for analysis of the peak stress data a set of 3 replicates had to be produced from mean and standard deviation data for each material at each time point as the complete raw data were not available.

An interaction plot of the proportion of peak stress from baseline by material, degradation time and degradation environment demonstrated that main effects and two factor interactions were present so these were all included in a three-way ANOVA (n=3) of the proportional stress (see Appendix IV for proportional peak stress Minitab output). Only the main effect of the degradation environment and the two interactions involving degradation environment were not significant. This finding again supports the notion that the molecular weight change was not sufficient to generate a statistically significant change in the behavior of the materials measured by peak stress at the time points measured.

Further ANOVAs (n=3) performed on the two chemical composition groups confirm that the effect of degradation environment was not significant for either set of materials. Contrary to strain measurements, the effect of time and material (as well as the interaction between the two) was significant ($p < 0.01$) for the PLLA group suggesting that the change in molecular weight of these materials was sufficient to affect the stress behavior of the materials. The PLLA/PCL group was the same indicating differences between materials, differences with increasing degradation time and different rates of behavior change over time for all the different materials measured.

Table 13: Results of one-way ANOVAs of proportional peak stress by degradation time (Note: x means the difference between 95% confidence intervals included zero)

Results of One-way ANOVAs of Proportional Peak Stress by Degradation Time				
Material	p-value	2 weeks vs. 4 weeks	2 weeks vs. 8 weeks	4 weeks vs. 8 weeks
1	0.121	x	x	x
2	0.000			
3	0.017	x		
4	0.000			
5	0.000	x		
6	0.000			
7	0.000			
8	0.000			
9	0.000			
10	0.000			
11	0.000			
12	0.000			
13	0.000			
14	0.000	x		
15	0.003	x		x
16	0.000	x		
17	0.006	x		

One-way ANOVAs for each individual material (excluding material 18) by time (n=6) were performed for proportional peak stress. PLLA materials 1 and 3 were not significantly different ($p > 0.01$) over the 8 week degradation period. This would suggest that any changes in molecular weight did not significantly affect the stress behavior of these materials. When comparing 95% confidence intervals (CIs) for each material by degradation time several materials, PLLAs 1 and 3 as well as PLLA/PCLs 5, 14, 15, 16 and 17 did not significantly change between 2 weeks and 4 weeks. This would suggest that the rate of change related to degradation time for these materials was slightly slower for these materials until the 4 week time point.

Conclusions and Recommendations

Initial visual inspection, SEM images and DSC data did not single out any particular material for recommendation as a bioresorbable material for congenital heart defect repair. However, the PGA material (material 18) would not be recommended as an implantable material based on these tests as it did not maintain any kind of structural integrity beyond a 2 week period. It might be a candidate if it can be processed in such a way that it does not unravel but then it would need to be retested as no tests could be performed on this material after 4 weeks and no strength testing was possible after 2 weeks. The slight degradation related changes visible in the SEM images of materials 4 through 17 suggest that these materials may be appropriate for bioresorbable materials as the changes noted may promote tissue ingrowth. Further in vitro and in vivo testing would be necessary to confirm this. With the exception of the PGA material and possibly the PLLA/PCL sponge material 14, no major damage or large pieces of material broke off of the material samples. Major damage such as this would rule out a material as large pieces degrading into the blood stream could potentially create an embolism or stroke.

GPC measurements of all the materials suggest that there was molecular weight change with degradation. The magnitude of degradation depended on the individual material properties, degradation time and degradation environment for all the materials except possibly material 4, the PLLA BIOFELT, which maintained molecular weights very near baseline values. The magnitude changes were statistically significant for all the main factors of material, degradation time and degradation environment ($p < 0.01$). The change in molecular weight within the first 2 to 8 weeks would theoretically be beneficial, potentially allowing for tissue ingrowth.

PLLA film material 3 was the only material tested here to maintain its mechanical properties over the 8 week degradation time period as measured by peak strain and peak stress. PLLA film material 1 maintained its stress behavior and PLLA BIOFELT material 4 and PLLA/PCL materials 5 through 7 all maintained their strain behavior over the 8 weeks degradation time. The materials that maintained at least one of these mechanical measurements over time would be the strongest candidates for further testing. The other materials may still be acceptable depending on how much of a difference (statistically significant or not) is acceptable. For instance, PLLA BIOFELT material 4 maintained its strain performance but not its stress performance and the baseline value for the material was on the order of human cardiac tissue tensile strength (Chen et al., 2008) so a significant decrease from that value does not make it a strong candidate for congenital heart defect repair. The other materials tested here all had peak stress values at least an order of magnitude greater than human cardiac tissue but less than collagen so these materials may still not be appropriate (Chen et al., 2008). In addition, there were only enough samples to test these materials in one direction so if any materials are anisotropic further testing would be required.

Although the results from these tests are inconclusive regarding specific recommendations for bioresorbable materials for congenital heart defect repair there are a few important results. First, the exact morphology and chemical composition of the material does have a significant effect on the degradation rate as measured by the change in molecular weight over time. This suggests that if an ideal degradation rate is determined for the cardiac environment the PLLA and/or PLLA/PCL materials investigated here could be manufactured in a specific morphology to closely match the desired degradation profile. In addition, there were a few materials that maintained their stress and strain behavior for several weeks which suggest it is possible for these materials to undergo some degradation while maintaining mechanical properties for up to 8 weeks when it is thought that endothelialization and tissue ingrowth should be in progress. Further testing would be required to see for how long the mechanical strength is maintained. It is recommended that further testing include testing materials at longer degradation time points; to at least 24 weeks up to 2 years if possible, to get a profile for degradation behavior out to the time point where it is thought that complete endothelialization and tissue ingrowth are solidly underway and/or complete (Sigler & Jux, 2007). In addition, testing of the mechanical properties of atrial septal tissue itself would be very helpful in determining if the mechanical properties of these materials are appropriate and what are the minimal properties required for atrial septal wall and device integrity to be maintained during the ingrowth process.

As there were significant differences in molecular weight, but not peak stress and strain measurements, the inclusion of an agitated or dynamic degradation environment is still recommended. Especially for degradation in a dynamic environment of a beating heart one would ideally test degradation beyond agitation at 80 RPM and include testing with solution flowing across the material and/or the materials being agitated against another surface that would simulate the placement of these materials flush with cardiac septal tissue to get a more accurate agitated environment measure. In addition, this testing was completed in a relatively constant (minor fluctuations in pH), inert solution of phosphate buffered saline. If bioresorbable materials are to be successfully implanted and resorbed, testing that includes representations of immune system response and other blood factors should be completed in vitro first. For instance, one could add the enzymes present in the blood stream, such as lipase, to see if active components significantly change the degradation characteristics of these materials. One should also determine the tissue ingrowth feasibility further by attempting to seed the materials with cells to determine if tissue ingrowth is likely to be successful.

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Appendices

Appendix I: DSC

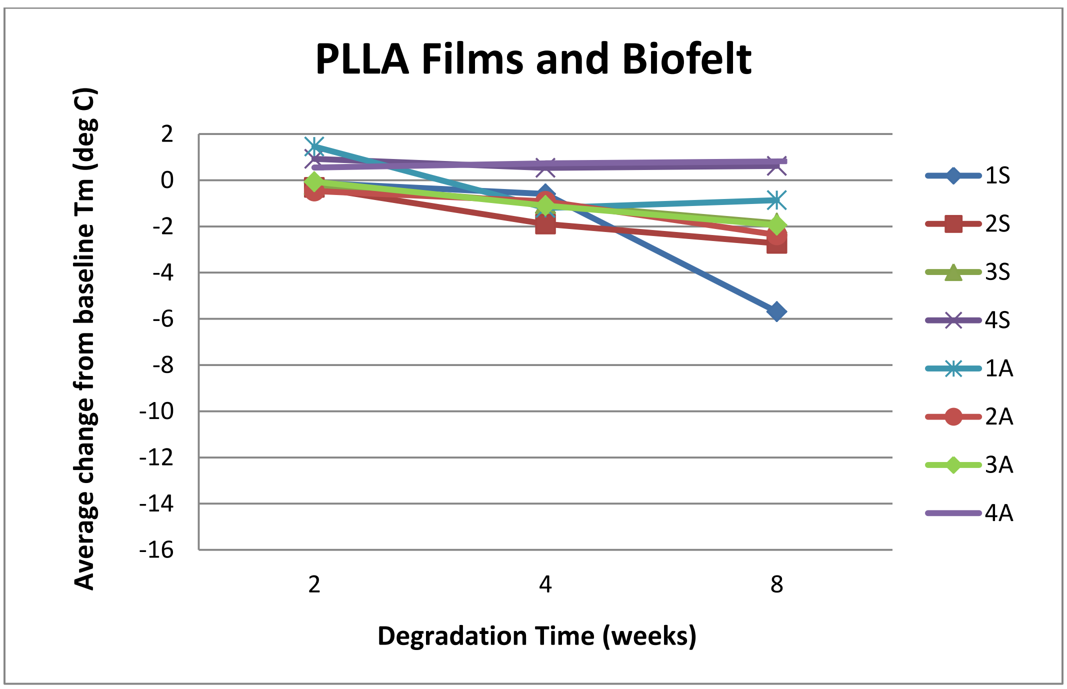

Figure 35: Average change from baseline Tm for PLLA films and biofelt

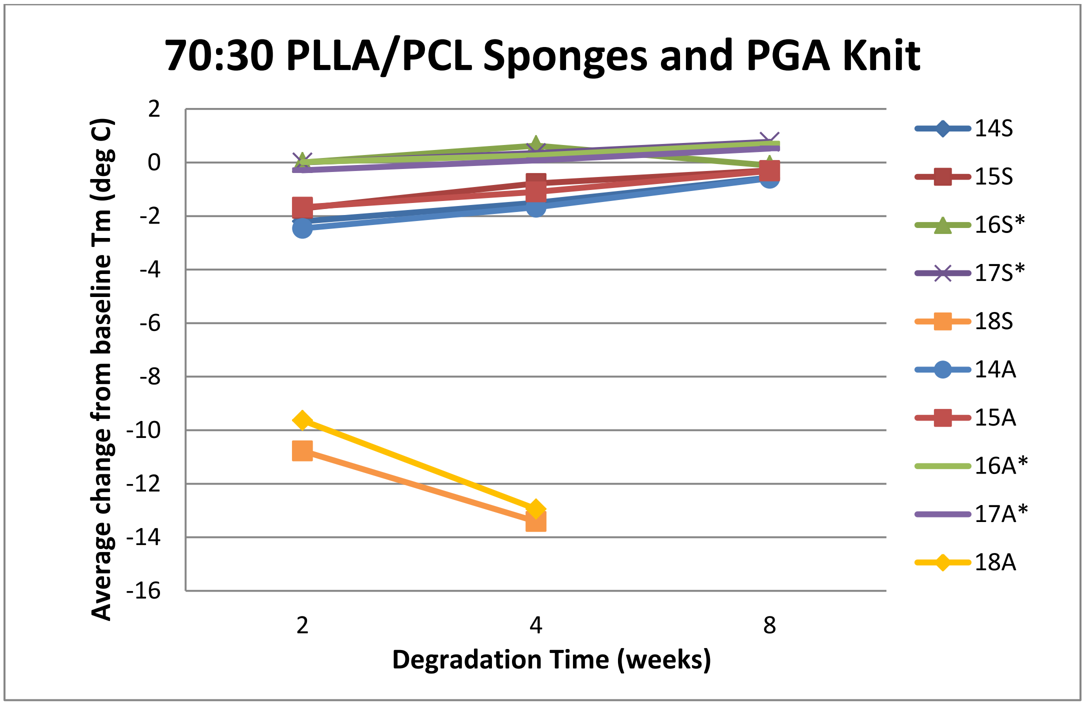

Figure 36: Average change from baseline Tm for 70:30 PLLA/PCL sponges and PGA knit
Note: material 18 has no 8S or 8A data

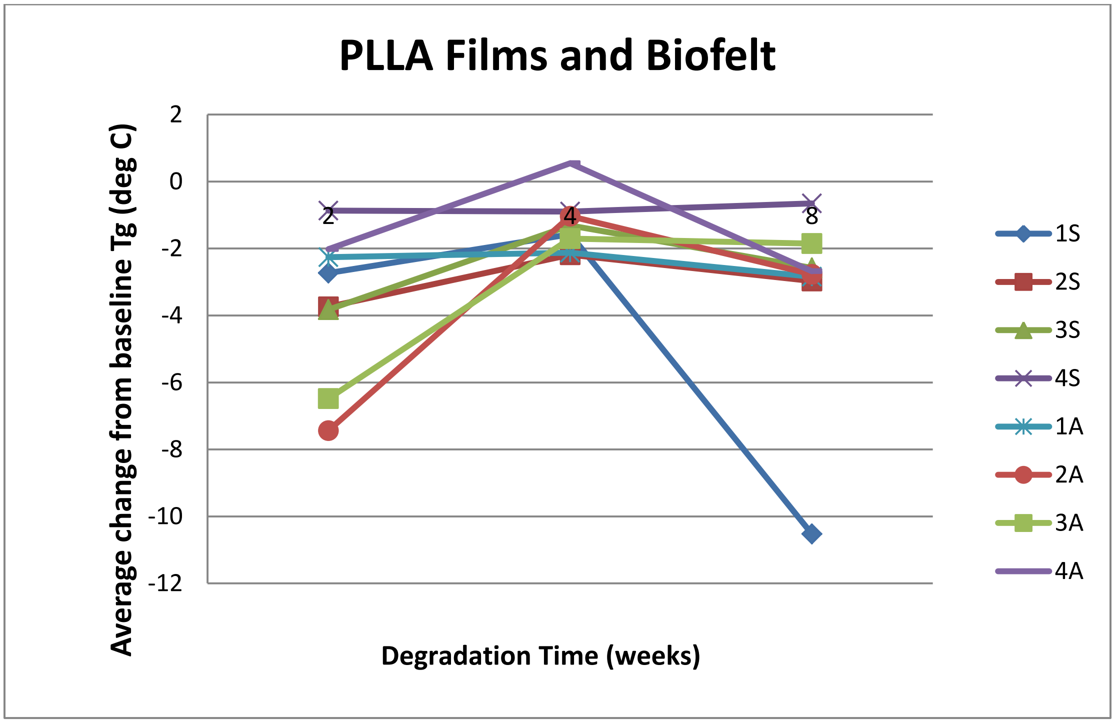

Figure 37: Average change from baseline Tg for PLLA films and Biofelt (Note: this is a different scale)

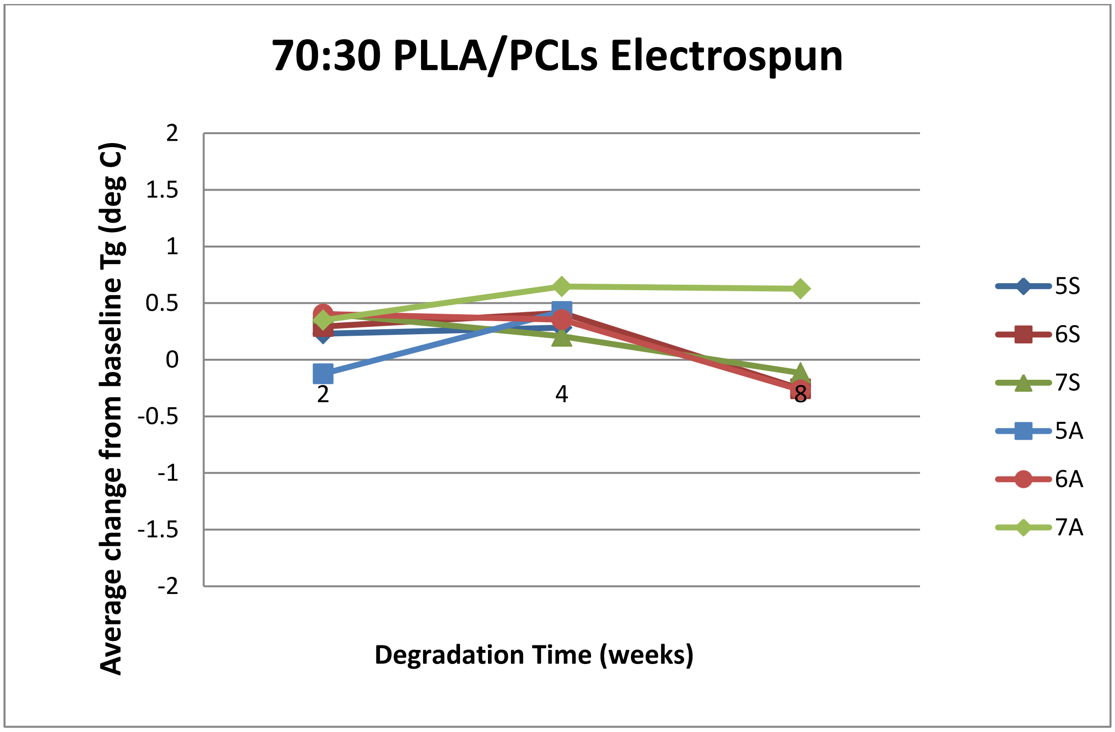

Figure 38: Average change from baseline Tg for electrospun 70:30 PLLA/PCL

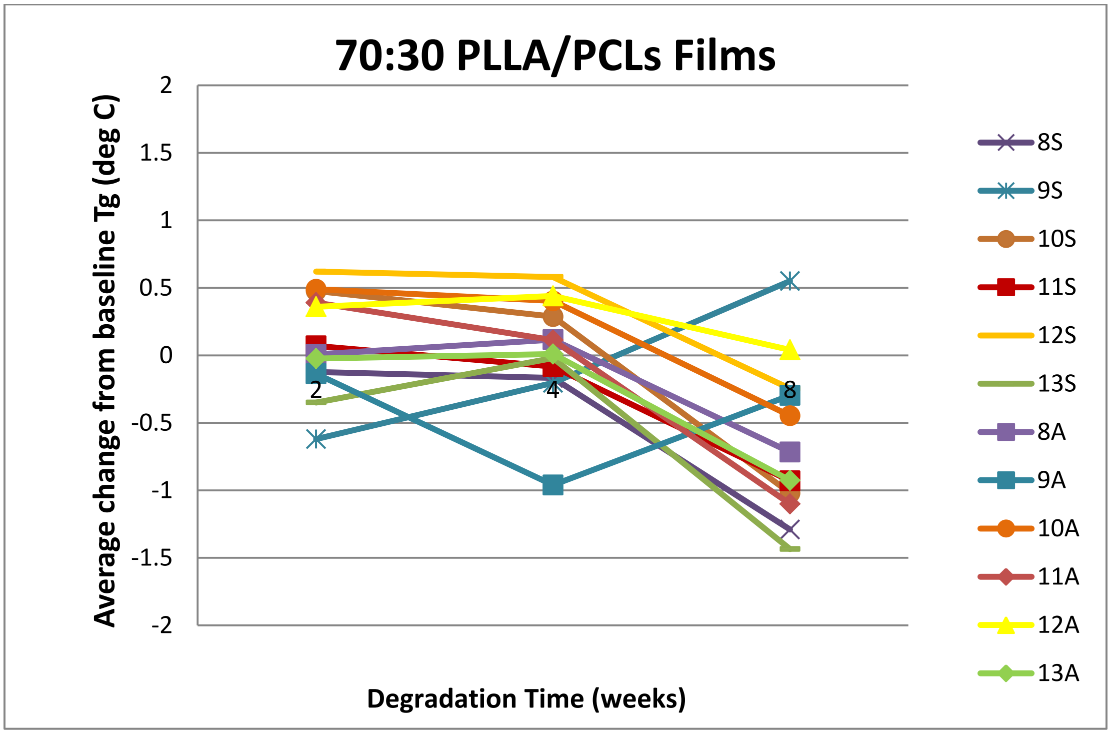

Figure 39: Average change from baseline Tg of 70:30 PLLA/PCL films

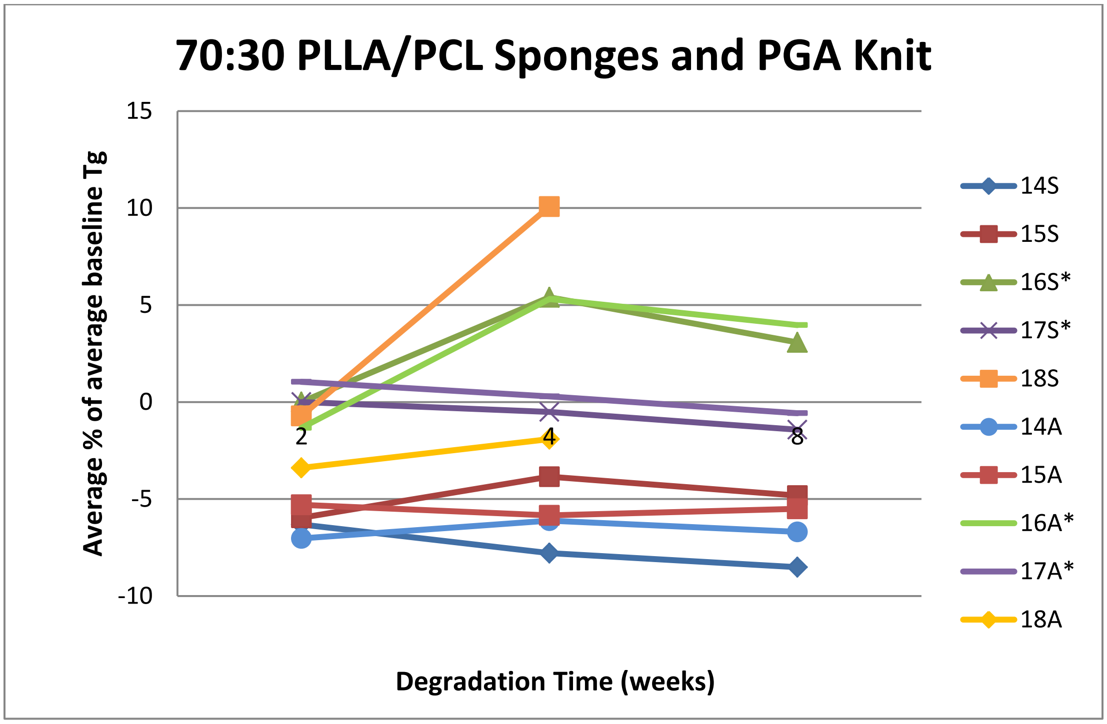

Figure 40: Average change from baseline Tg for 70:30 PLLA/PCL sponges and PGA knit (Note: this is a different scale)

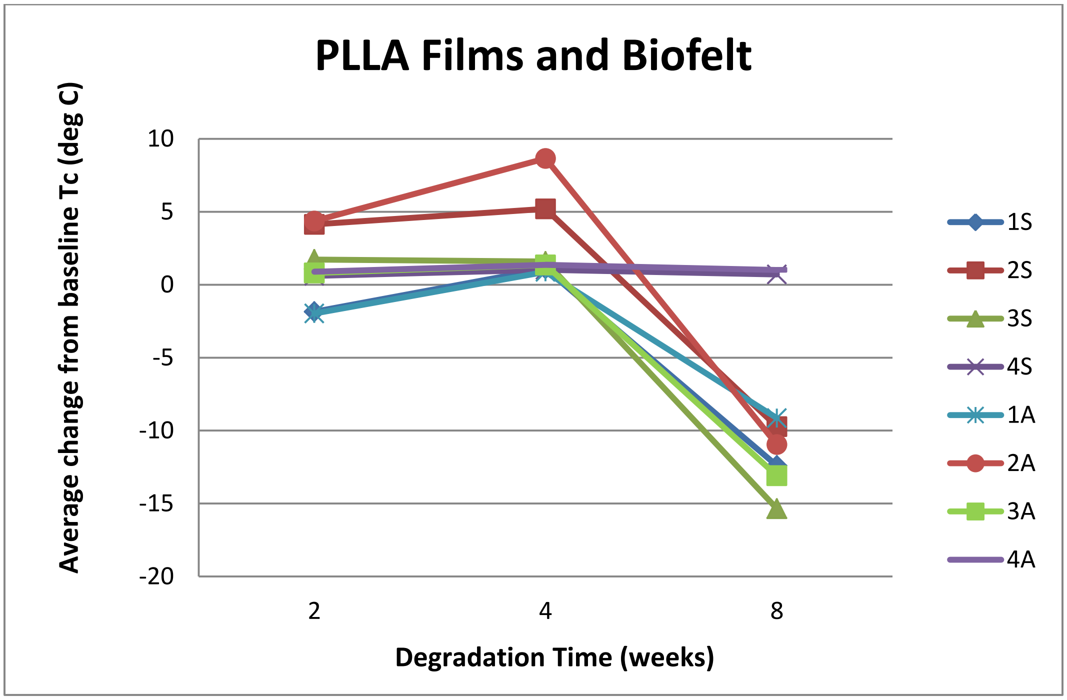

Figure 41: Average change from baseline Tc for PLLA films and Biofelt samples

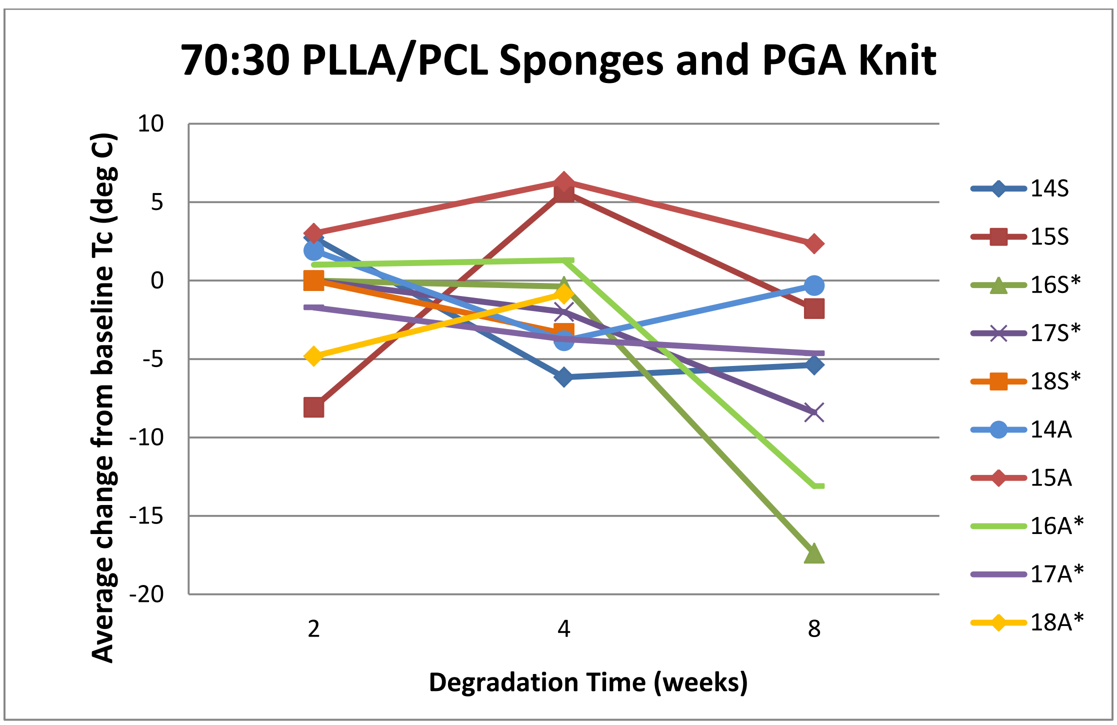

Figure 42: Average change from baseline Tc for 70:30 PLLA/PCL sponges and PGA knit samples

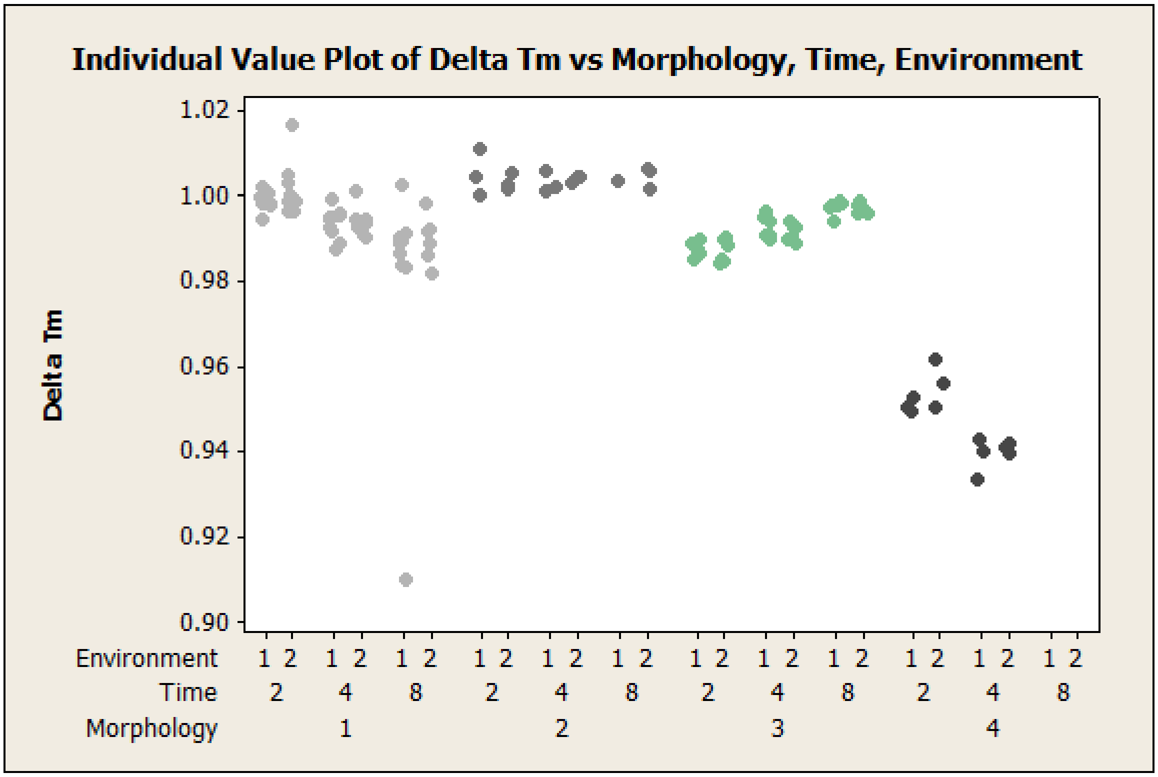

Figure 43: Individual value plot of the change in Tm by morphology, degradation time and degradation environment

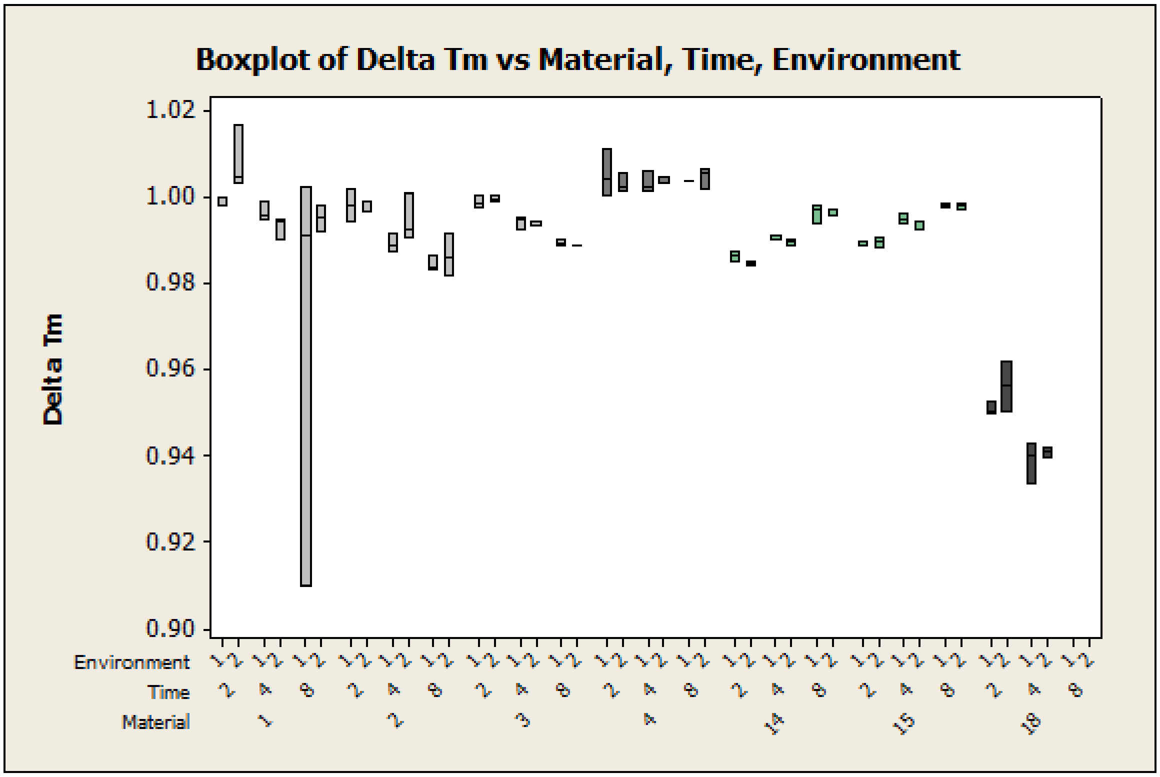

Figure 44: Boxplot of the change in Tm by material, degradation time and degradation environment

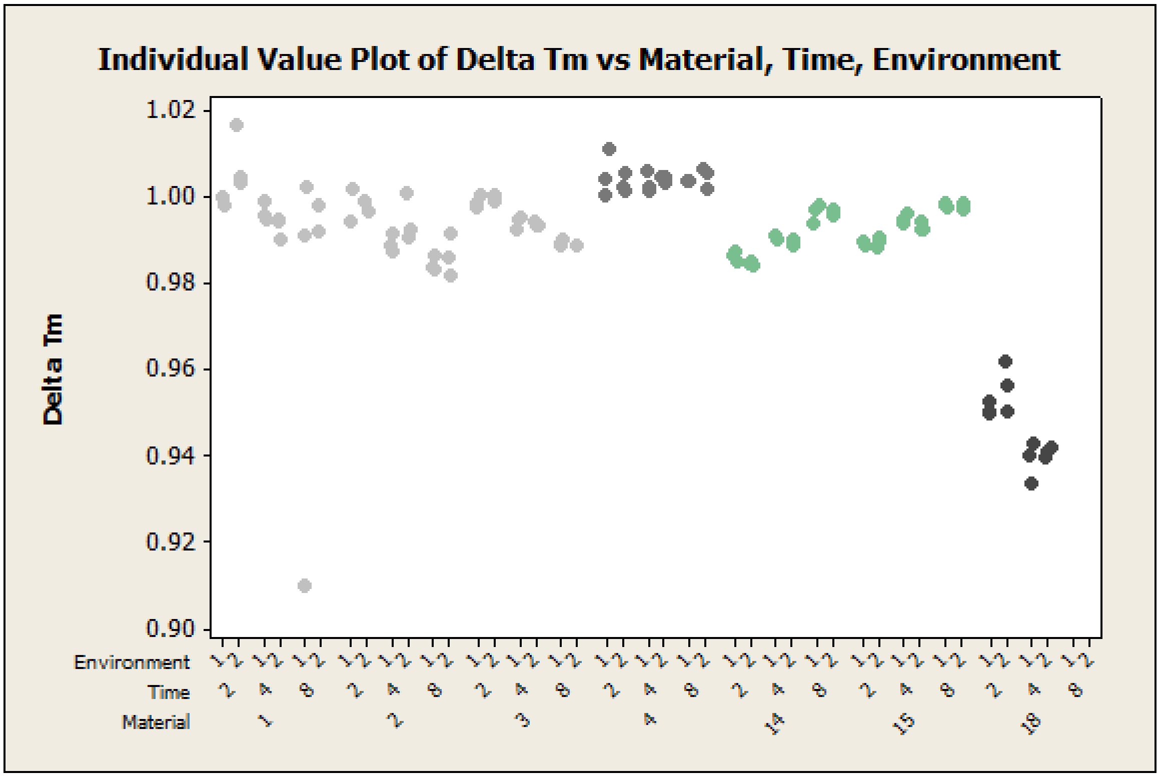

Figure 45: Individual value plot of the change in Tm by material, degradation time and degradation environment

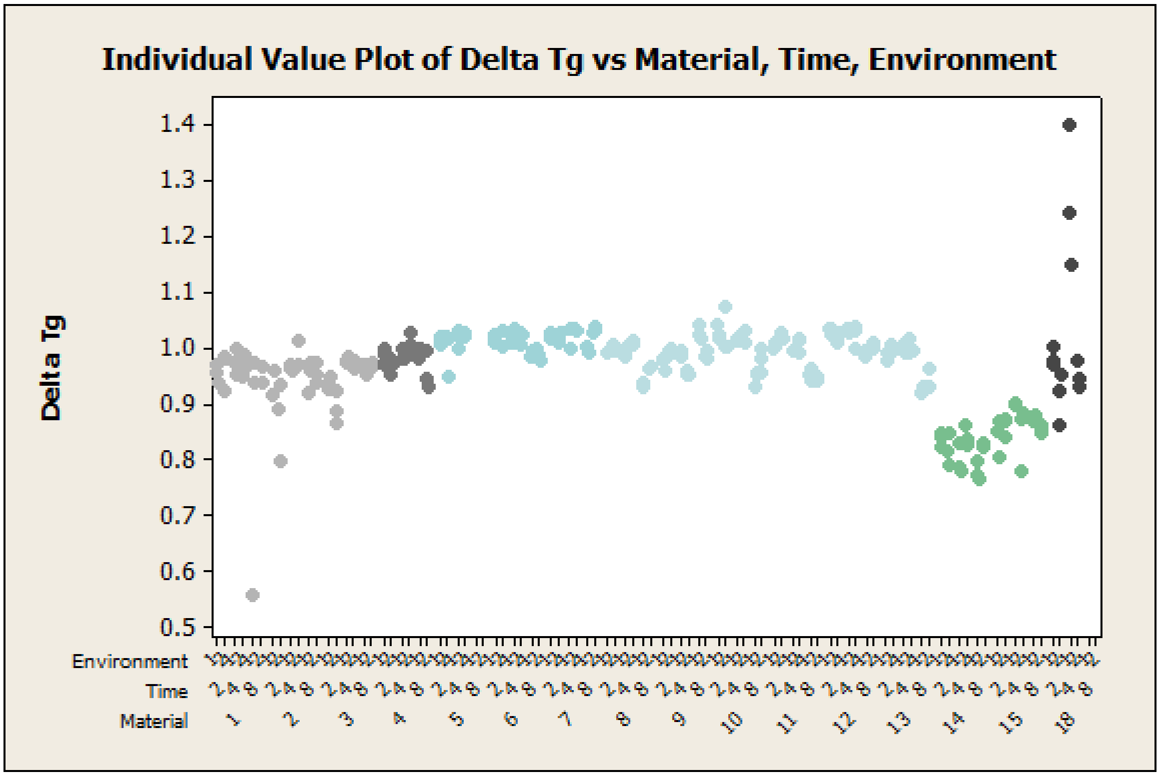

Figure 46: Individual value plot of the change in Tg by material, degradation time and degradation environment

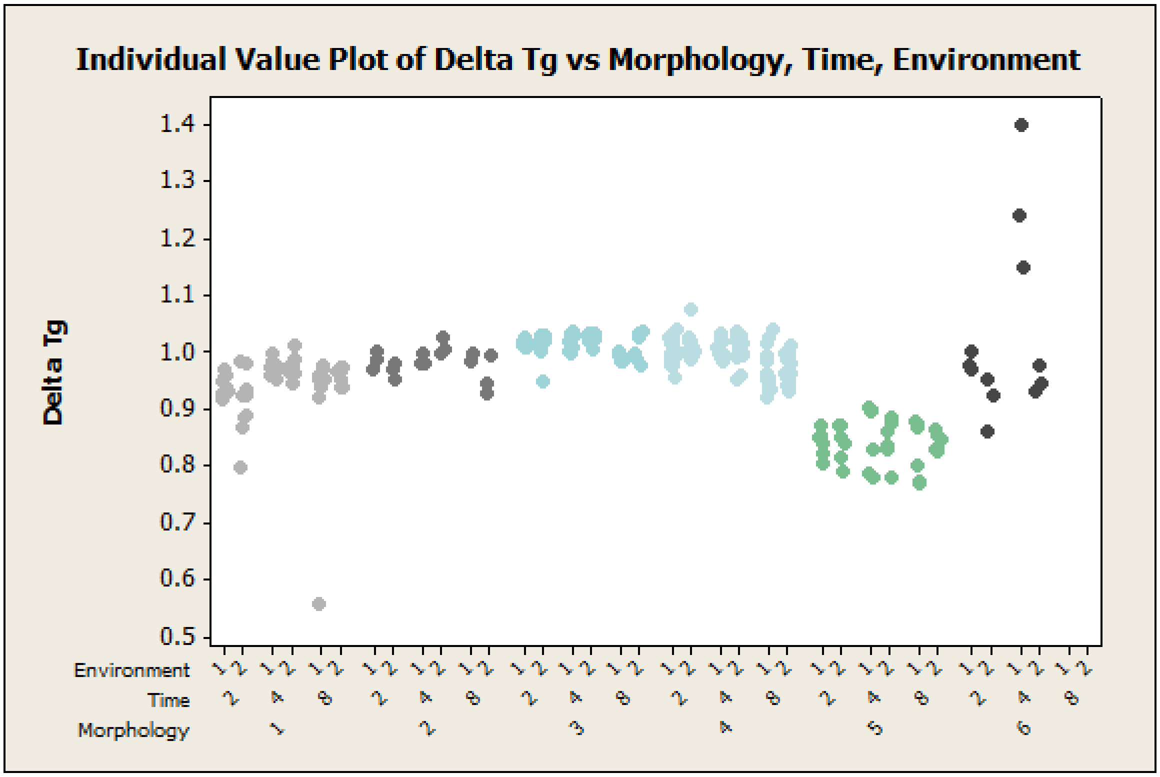

Figure 47: Individual value plot of the change in Tg by morphology, degradation time and degradation environment

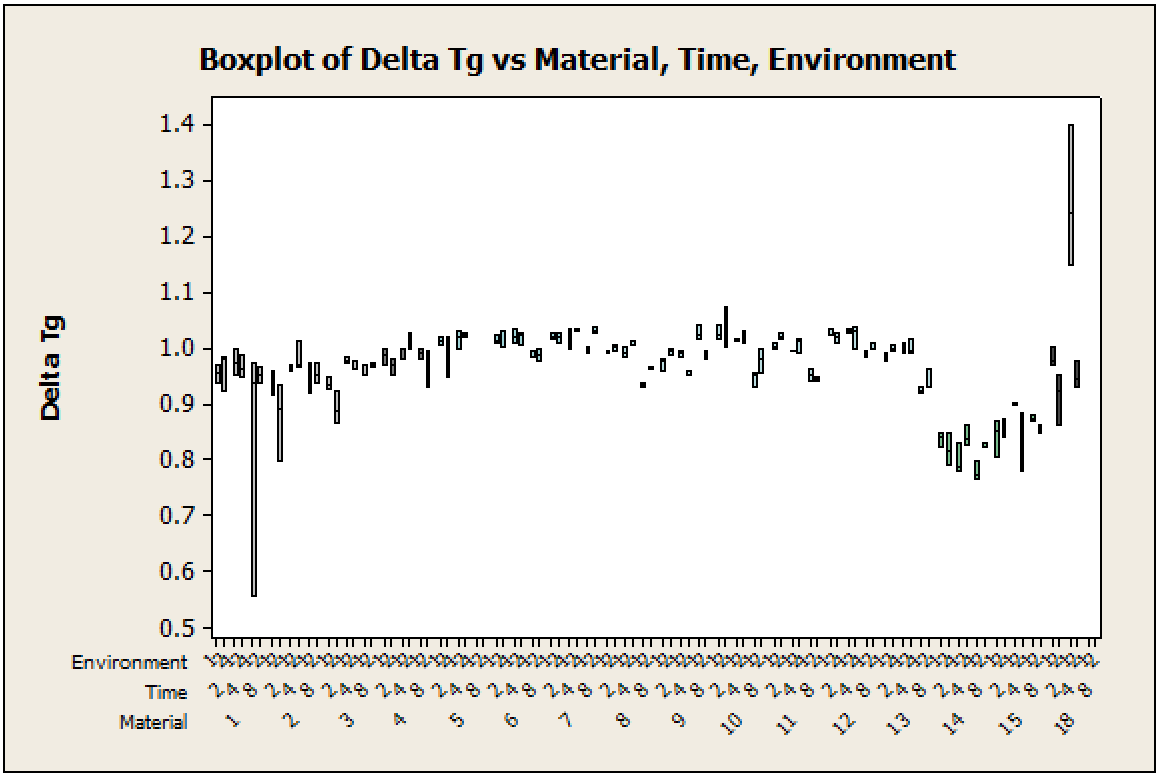

Figure 48: Boxplot of the change in Tg by material, degradation time and degradation environment

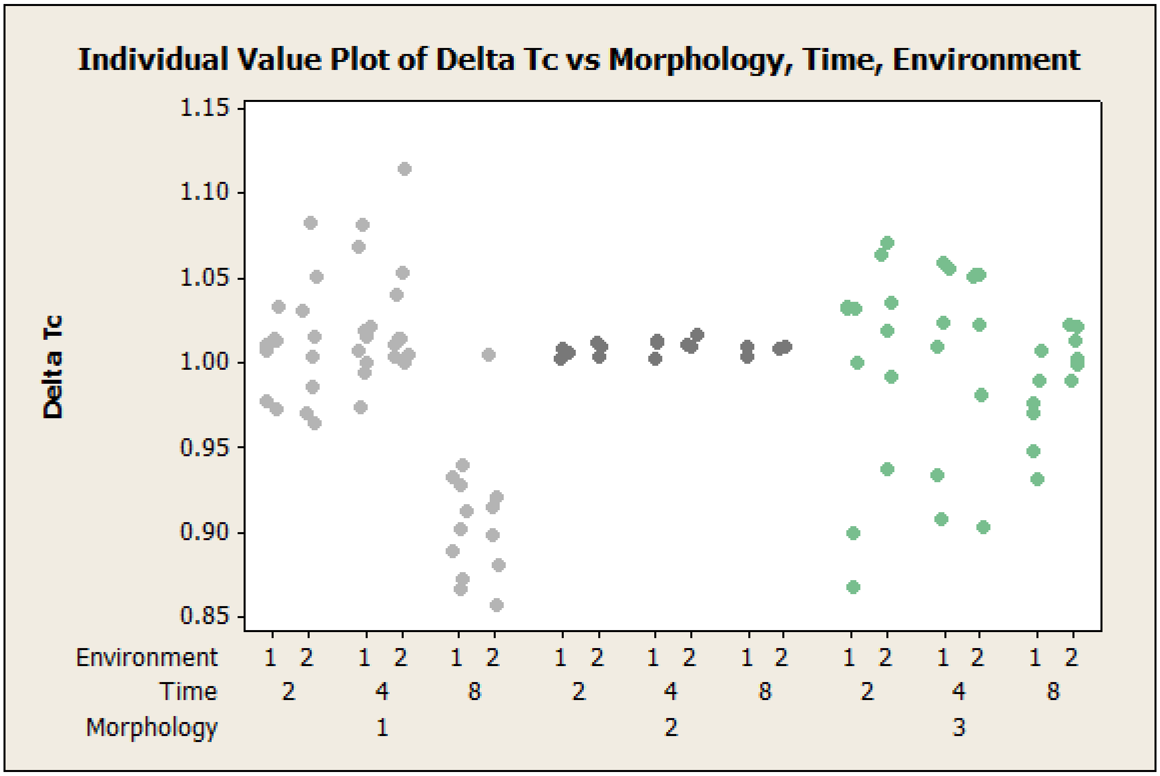

Figure 49: Individual value plot of the change in Tc by morphology, degradation time and degradation environment

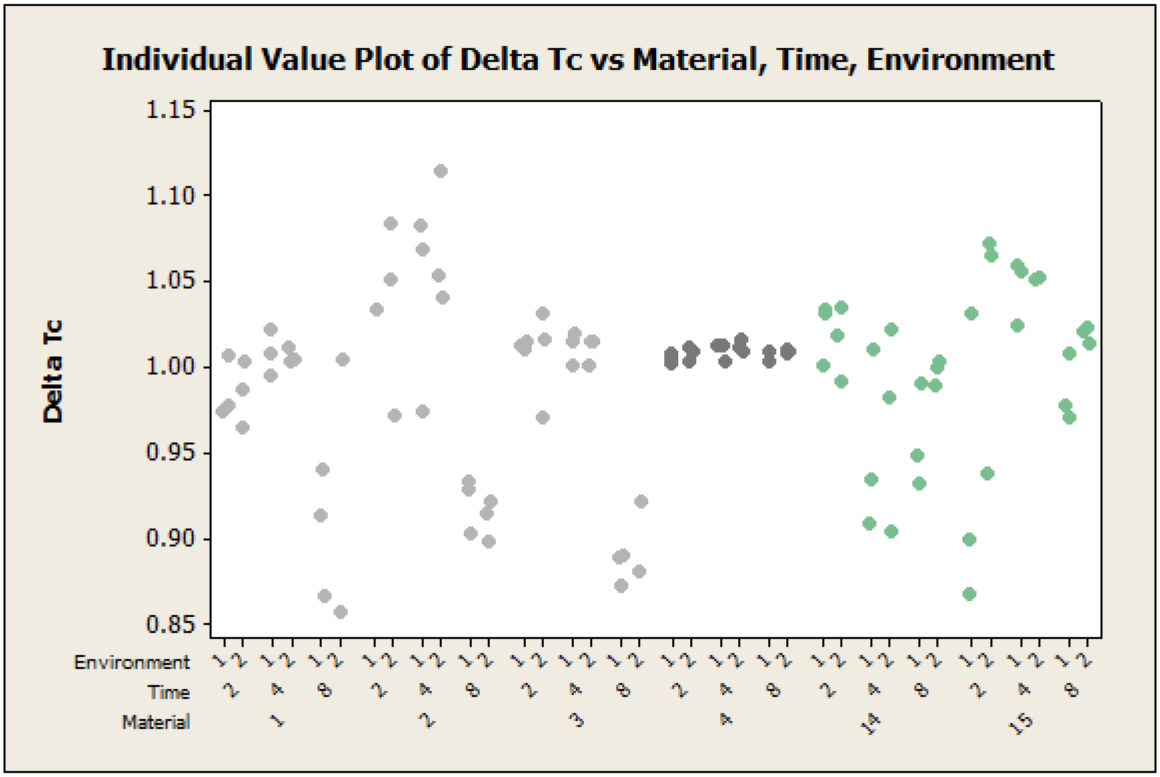

Figure 50: Individual value plot of the change in Tc by material, degradation time and degradation environment

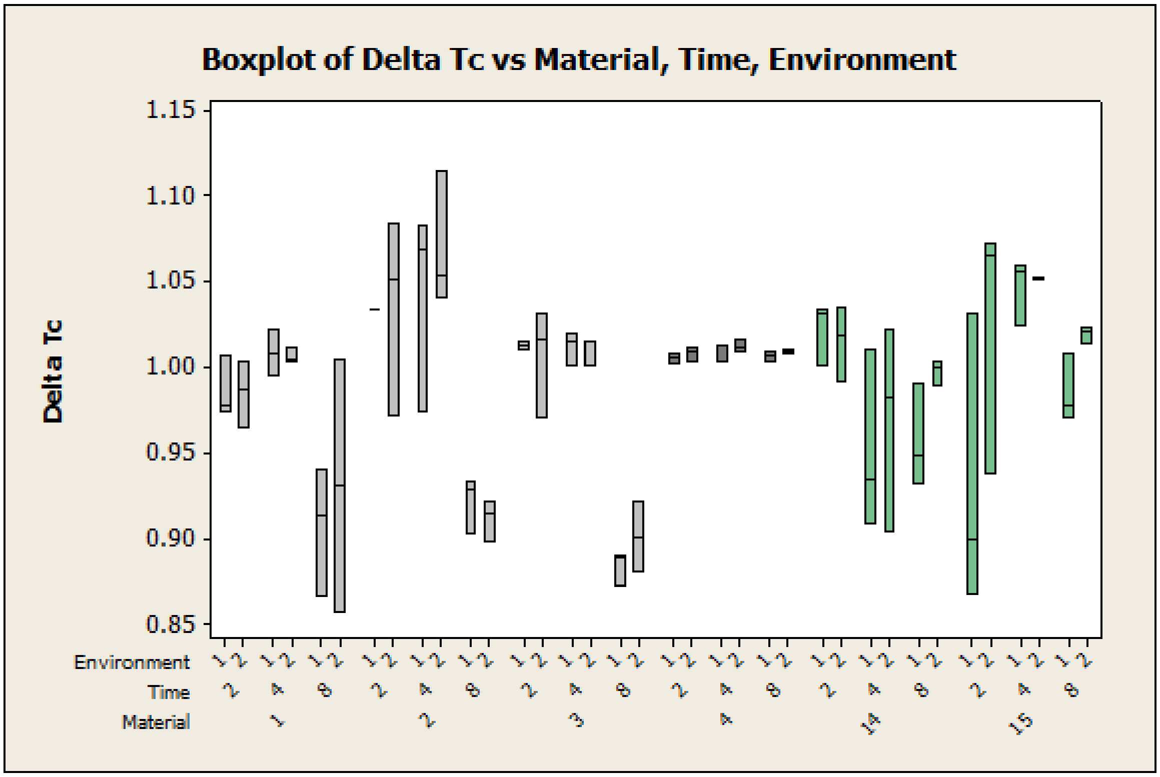

Figure 51: Individual value plot of the change in Tc by material, degradation time and degradation environment

Appendix II: GPC Results

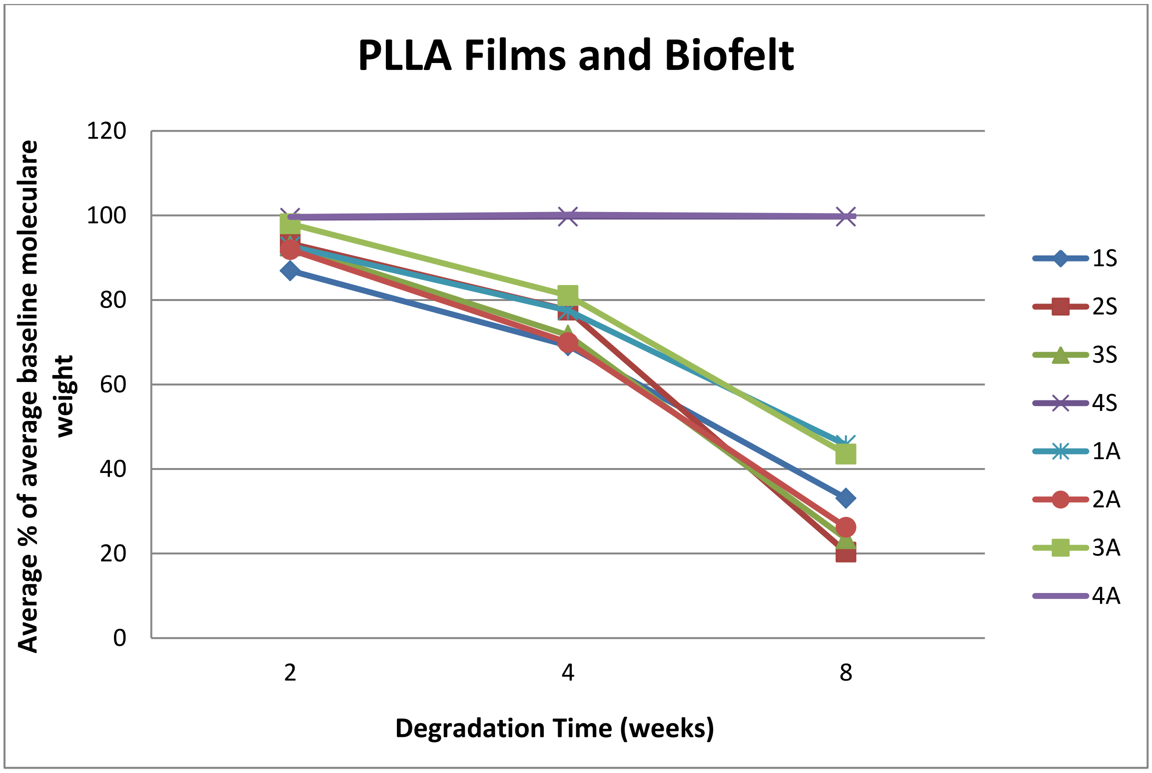

Figure 52: Average percent of average molecular weight at baseline for PLLA films and Biofelt samples

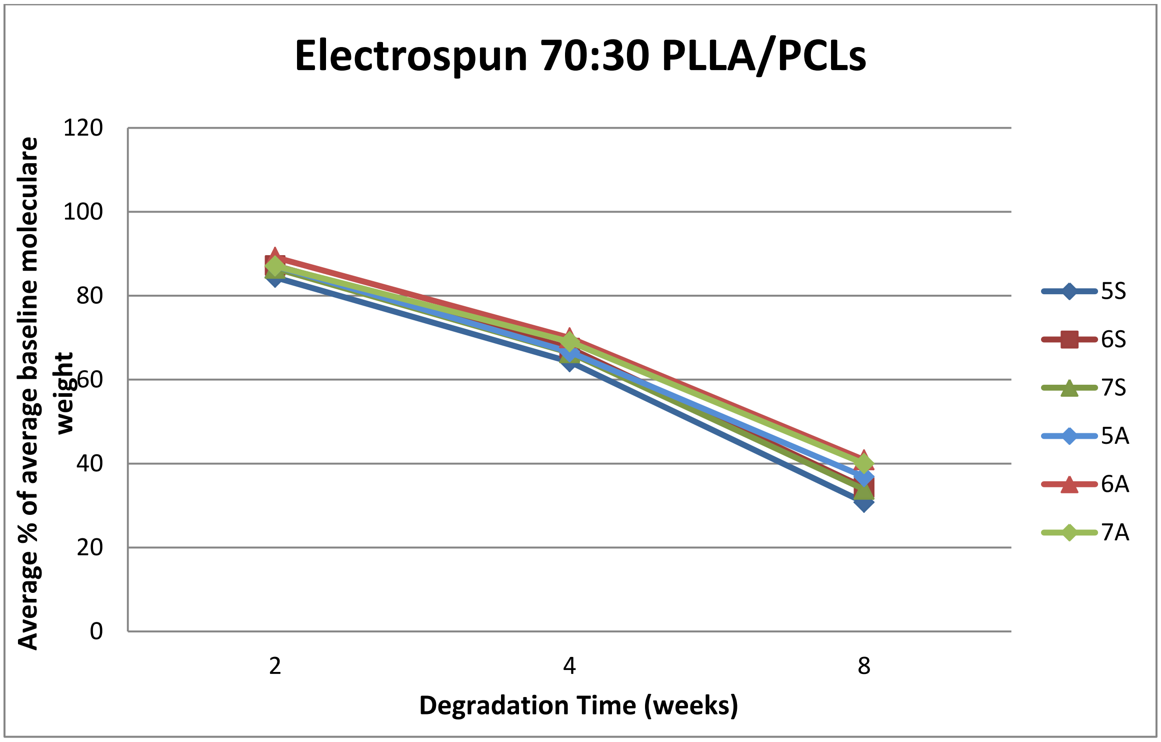

Figure 53: Average percent of average molecular weight at baseline for 70:30 PLLA/PCL electrospun samples

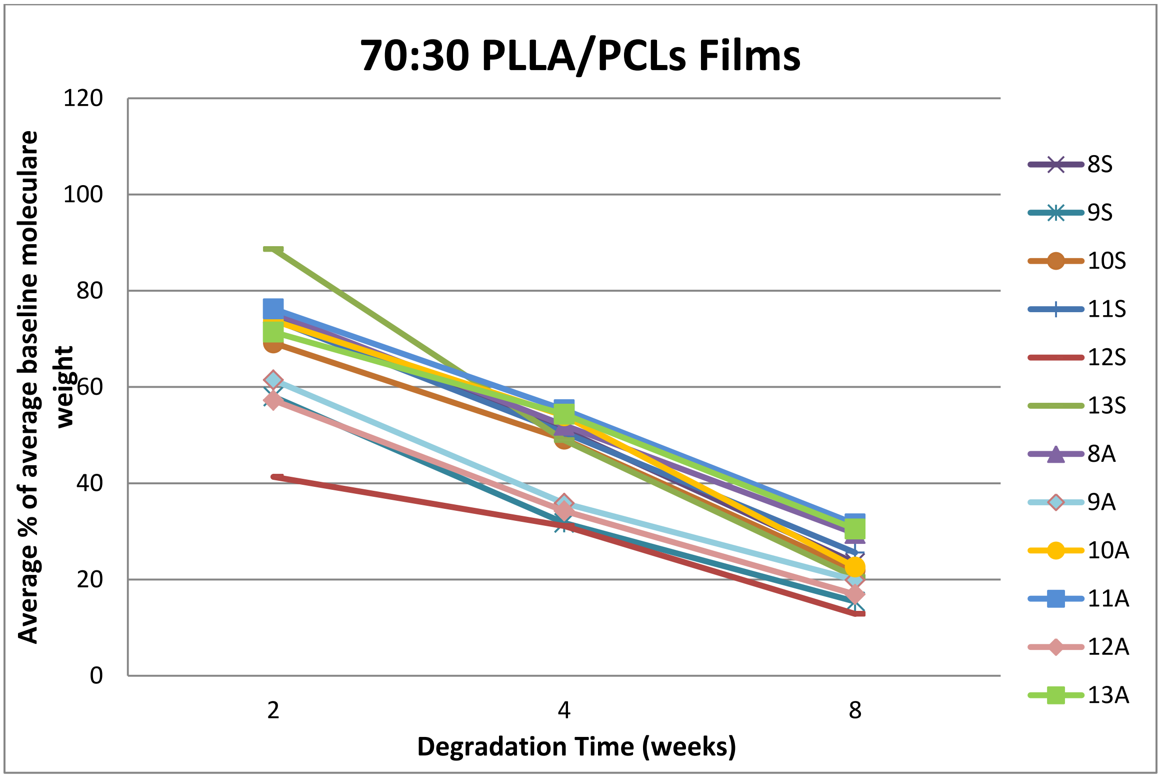

Figure 54: Average percent of average molecular weight at baseline for 70:30 PLLA/PCL film samples.

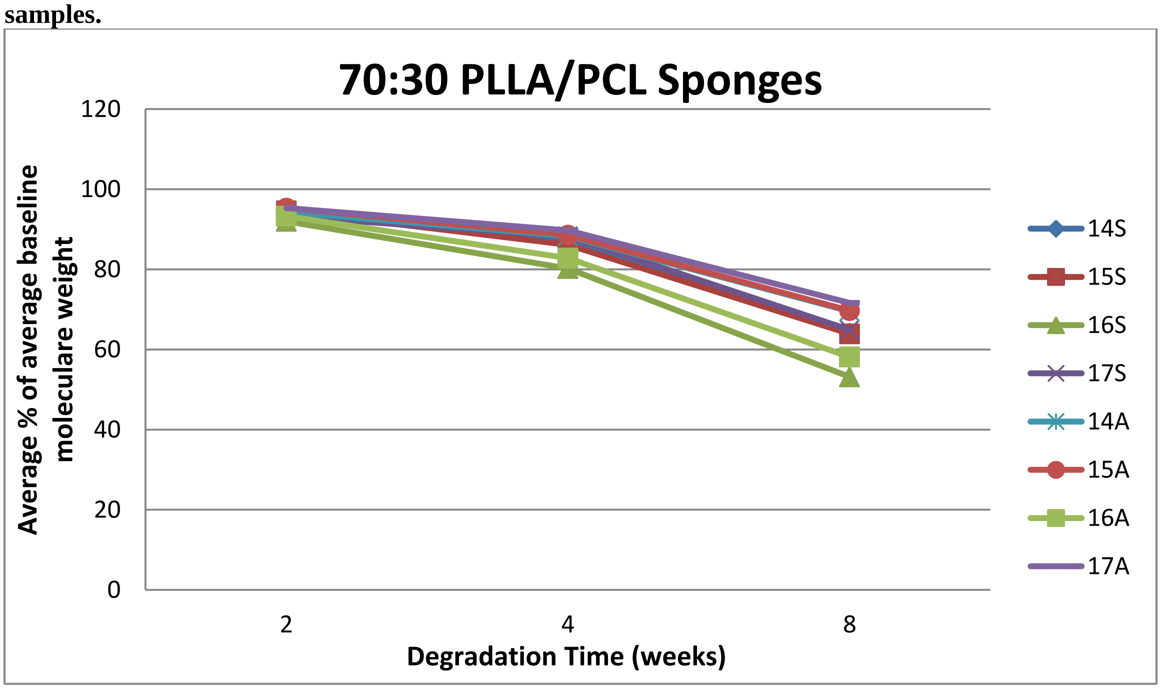

Figure 55: Average percent of average molecular weight at baseline of 70:30 PLLA/PCL sponge samples.

GPC Summary Statistics Output from Minitab:

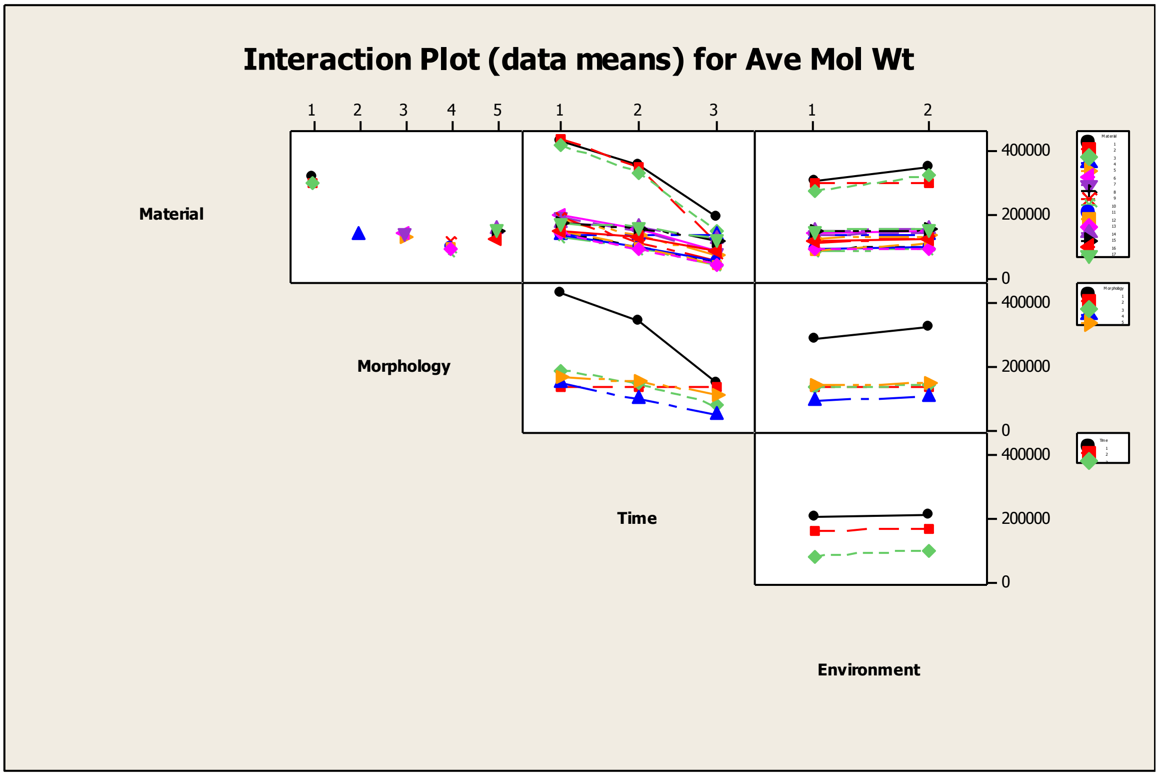

Figure 56: Interaction plot for the proportional molecular weight data, all materials

Descriptive Statistics: Mol Wt Prop

Results for Material = 1, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.8693	0.0273	0.0473	0.8197	0.8197	0.8743
	4	3	0	0.6923	0.0744	0.1288	0.5585	0.5585	0.7029
	8	3	0	0.331	0.144	0.249	0.169	0.169	0.206

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.9140	0.9140
	4	0.8156	0.8156
	8	0.617	0.617

Results for Material = 1, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.9273	0.0185	0.0320	0.8927	0.8927	0.9334
	4	3	0	0.77518	0.00821	0.01421	0.76341	0.76341	0.77116
	8	3	0	0.458	0.104	0.180	0.263	0.263	0.490

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.9558	0.9558
	4	0.79097	0.79097
	8	0.619	0.619

Results for Material = 2, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.9339	0.0119	0.0207	0.9208	0.9208	0.9232
	4	3	0	0.7762	0.0315	0.0546	0.7264	0.7264	0.7675
	8	3	0	0.2036	0.0177	0.0307	0.1687	0.1687	0.2161

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.9577	0.9577
	4	0.8346	0.8346
	8	0.2261	0.2261

Results for Material = 2, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.9193	0.0122	0.0211	0.9017	0.9017	0.9136
	4	3	0	0.69946	0.00842	0.01458	0.68289	0.68289	0.70512
	8	3	0	0.2625	0.0113	0.0195	0.2505	0.2505	0.2520

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.9427	0.9427
	4	0.71037	0.71037
	8	0.2850	0.2850

Results for Material = 3, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.92810	0.00485	0.00840	0.92015	0.92015	0.92727
	4	3	0	0.7169	0.0371	0.0643	0.6599	0.6599	0.7043
	8	3	0	0.2353	0.0266	0.0460	0.1995	0.1995	0.2191

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.93688	0.93688
	4	0.7866	0.7866
	8	0.2872	0.2872

Results for Material = 3, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.9803	0.0316	0.0548	0.9321	0.9321	0.9689
	4	3	0	0.8105	0.0199	0.0344	0.7712	0.7712	0.8249
	8	3	0	0.4353	0.0729	0.1263	0.3273	0.3273	0.4044

Variable	Time	Q3	Maximum
Mol Wt Prop	2	1.0398	1.0398
	4	0.8354	0.8354
	8	0.5741	0.5741

Results for Material = 4, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.99465	0.00291	0.00504	0.98931	0.98931	0.99530
	4	3	0	0.99731	0.00116	0.00201	0.99530	0.99530	0.99731
	8	3	0	0.99732	0.00232	0.00402	0.99330	0.99330	0.99731

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.99932	0.99932
	4	0.99932	0.99932
	8	1.00134	1.00134

Results for Material = 4, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.99665	0.00242	0.00419	0.99330	0.99330	0.99530
	4	3	0	1.0020	0.00441	0.00764	0.9933	0.9933	1.0054
	8	3	0	0.99798	0.00134	0.00232	0.99530	0.99530	0.99932

Variable	Time	Q3	Maximum
Mol Wt Prop	2	1.00134	1.00134
	4	1.0074	1.0074
	8	0.99932	0.99932

Results for Material = 5, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.8440	0.0182	0.0316	0.8088	0.8088	0.8532
	4	3	0	0.64284	0.00489	0.00848	0.63381	0.63381	0.64409
	8	3	0	0.3077	0.0162	0.0280	0.2915	0.2915	0.2915

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.8699	0.8699
	4	0.65063	0.65063
	8	0.3400	0.3400

Results for Material = 5, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.8708	0.0131	0.0228	0.8495	0.8495	0.8680
	4	3	0	0.6661	0.0207	0.0358	0.6250	0.6250	0.6831
	8	3	0	0.3686	0.0175	0.0302	0.3459	0.3459	0.3570

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.8948	0.8948
	4	0.6902	0.6902
	8	0.4030	0.4030

Results for Material = 6, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.87221	0.000638	0.00110	0.87093	0.87093	0.87285
	4	3	0	0.67502	0.00283	0.00490	0.67038	0.67038	0.67454
	8	3	0	0.34333	0.00153	0.00265	0.34151	0.34151	0.34212

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.87285	0.87285
	4	0.68015	0.68015
	8	0.34637	0.34637

Results for Material = 6, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.89166	0.00628	0.01087	0.88443	0.88443	0.88638
	4	3	0	0.6995	0.0114	0.0197	0.6773	0.6773	0.7061
	8	3	0	0.40865	0.00305	0.00528	0.40365	0.40365	0.40812

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.90417	0.90417
	4	0.7150	0.7150
	8	0.41417	0.41417

Results for Material = 7, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.86507	0.00698	0.01209	0.85129	0.85129	0.87005
	4	3	0	0.66396	0.00538	0.00931	0.65668	0.65668	0.66073
	8	3	0	0.33842	0.00200	0.00347	0.33448	0.33448	0.33979

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.87386	0.87386
	4	0.67445	0.67445
	8	0.34099	0.34099

Results for Material = 7, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.87074	0.00647	0.01120	0.86248	0.86248	0.86626
	4	3	0	0.6903	0.0127	0.0221	0.6648	0.6648	0.7015
	8	3	0	0.39984	0.00863	0.01495	0.38421	0.38421	0.40132

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.88349	0.88349
	4	0.7044	0.7044
	8	0.41400	0.41400

Results for Material = 8, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.74313	0.00429	0.00743	0.73459	0.73459	0.74664
	4	3	0	0.51078	0.00290	0.00502	0.50510	0.50510	0.51267

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
	8	3	0	0.23446	0.00916	0.01587	0.21614	0.21614	0.24323

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.74816	0.74816
	4	0.51459	0.51459
	8	0.24401	0.24401

Results for Material = 8, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.75383	0.00593	0.01028	0.74512	0.74512	0.75122
	4	3	0	0.52059	0.00927	0.01606	0.50416	0.50416	0.52136
	8	3	0	0.29567	0.00521	0.00903	0.28631	0.28631	0.29637

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.76517	0.76517
	4	0.53626	0.53626
	8	0.30433	0.30433

Results for Material = 9, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1
Mol Wt Prop	2	3	0	0.57992	0.00474	0.00822	0.57195	0.57195
	4	3	0	0.31760	0.00145	0.00250	0.31560	0.31560
	8	3	0	0.15408	0.000361	0.000626	0.15342	0.15342

Variable	Time	Median	Q3	Maximum
Mol Wt Prop	2	0.57945	0.58836	0.58836
	4	0.31679	0.32041	0.32041
	8	0.15417	0.15467	0.15467

Results for Material = 9, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.6146	0.0117	0.0203	0.5974	0.5974	0.6094
	4	3	0	0.35839	0.00254	0.00441	0.35330	0.35330	0.36093
	8	3	0	0.19891	0.00396	0.00686	0.19101	0.19101	0.20235

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.6369	0.6369
	4	0.36093	0.36093
	8	0.20338	0.20338

Results for Material = 10, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.69128	0.00376	0.00651	0.68625	0.68625	0.68897
	4	3	0	0.4914	0.0174	0.0301	0.4571	0.4571	0.5044
	8	3	0	0.21899	0.00793	0.01374	0.20830	0.20830	0.21418

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.69863	0.69863

	4	0.5128	0.5128
	8	0.23448	0.23448

Results for Material = 10, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.7380	0.0180	0.0311	0.7028	0.7028	0.7495
	4	3	0	0.5402	0.0105	0.0181	0.5244	0.5244	0.5363
	8	3	0	0.2261	0.0326	0.0565	0.1801	0.1801	0.2089

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.7618	0.7618
	4	0.5600	0.5600
	8	0.2892	0.2892

Results for Material = 11, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.74021	0.00451	0.00781	0.73570	0.73570	0.73570
	4	3	0	0.50529	0.00729	0.01262	0.49289	0.49289	0.50485
	8	3	0	0.25582	0.000625	0.00108	0.25500	0.25500	0.25541

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.74922	0.74922
	4	0.51812	0.51812
	8	0.25705	0.25705

Results for Material = 11, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.76215	0.00896	0.01552	0.74619	0.74619	0.76305
	4	3	0	0.55273	0.00931	0.01613	0.54291	0.54291	0.54393
	8	3	0	0.31559	0.00395	0.00684	0.30896	0.30896	0.31518

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.77720	0.77720
	4	0.57135	0.57135
	8	0.32263	0.32263

Results for Material = 12, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.41317	0.00952	0.01648	0.39414	0.39414	0.42227
	4	3	0	0.31136	0.00566	0.00980	0.30182	0.30182	0.31085
	8	3	0	0.12848	0.00495	0.00857	0.11859	0.11859	0.13312

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.42311	0.42311
	4	0.32140	0.32140
	8	0.13374	0.13374

Results for Material = 12, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.5723	0.0160	0.0278	0.5419	0.5419	0.5787
	4	3	0	0.3424	0.0112	0.0194	0.3268	0.3268	0.3362
	8	3	0	0.16905	0.00834	0.01444	0.15432	0.15432	0.16966

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.5963	0.5963
	4	0.3641	0.3641
	8	0.18318	0.18318

Results for Material = 13, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.88632	0.00326	0.00564	0.88140	0.88140	0.88508
	4	3	0	0.4896	0.0150	0.0260	0.4717	0.4717	0.4777
	8	3	0	0.2055	0.0104	0.0180	0.1928	0.1928	0.1976

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.89248	0.89248
	4	0.5193	0.5193
	8	0.2262	0.2262

Results for Material = 13, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.7141	0.0200	0.0347	0.6743	0.6743	0.7296
	4	3	0	0.5436	0.0127	0.0220	0.5193	0.5193	0.5489
	8	3	0	0.3048	0.0189	0.0327	0.2672	0.2672	0.3209

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.7384	0.7384
	4	0.5624	0.5624
	8	0.3263	0.3263

Results for Material = 14, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.94767	0.00511	0.00886	0.94158	0.94158	0.94359
	4	3	0	0.87437	0.00184	0.00318	0.87254	0.87254	0.87254
	8	3	0	0.63959	0.00253	0.00438	0.63544	0.63544	0.63916

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.95783	0.95783
	4	0.87805	0.87805
	8	0.64417	0.64417

Results for Material = 14, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.94361	0.00404	0.00700	0.93957	0.93957	0.93957
	4	3	0	0.88300	0.00328	0.00568	0.87805	0.87805	0.88174
	8	3	0	0.69568	0.00627	0.01086	0.68874	0.68874	0.69011

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.95169	0.95169
	4	0.88920	0.88920
	8	0.70820	0.70820

Results for Material = 15, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.94643	0.00308	0.00534	0.94240	0.94240	0.94441
	4	3	0	0.86146	0.000598	0.00104	0.86086	0.86086	0.86086
	8	3	0	0.63933	0.00378	0.00655	0.63191	0.63191	0.64179

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.95249	0.95249
	4	0.86266	0.86266
	8	0.64429	0.64429

Results for Material = 15, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.95318	0.00296	0.00512	0.94844	0.94844	0.95249
	4	3	0	0.88581	0.00223	0.00387	0.88271	0.88271	0.88456
	8	3	0	0.6972	0.0117	0.0202	0.6739	0.6739	0.7067

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.95860	0.95860
	4	0.89015	0.89015
	8	0.7109	0.7109

Results for Material = 16, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.9201	0.0105	0.0182	0.9037	0.9037	0.9168
	4	3	0	0.8020	0.0179	0.0310	0.7700	0.7700	0.8042
	8	3	0	0.53193	0.00406	0.00704	0.52397	0.52397	0.53445

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.9396	0.9396
	4	0.8319	0.8319
	8	0.53736	0.53736

Results for Material = 16, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.93269	0.00887	0.01536	0.91677	0.91677	0.93386
	4	3	0	0.82804	0.00387	0.00670	0.82197	0.82197	0.82691
	8	3	0	0.58154	0.00199	0.00345	0.57904	0.57904	0.58010

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.94742	0.94742
	4	0.83523	0.83523
	8	0.58547	0.58547

Results for Material = 17, Environment = 1

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.93229	0.00414	0.00717	0.92634	0.92634	0.93029
	4	3	0	0.88239	0.00284	0.00492	0.87868	0.87868	0.88053
	8	3	0	0.64927	0.00224	0.00388	0.64589	0.64589	0.64842

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.94025	0.94025
	4	0.88797	0.88797
	8	0.65351	0.65351

Results for Material = 17, Environment = 2

Variable	Time	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median
Mol Wt Prop	2	3	0	0.95307	0.00245	0.00424	0.94831	0.94831	0.95442
	4	3	0	0.89740	0.00475	0.00823	0.88797	0.88797	0.90117
	8	3	0	0.71634	0.00456	0.00790	0.70871	0.70871	0.71583

Variable	Time	Q3	Maximum
Mol Wt Prop	2	0.95647	0.95647
	4	0.90308	0.90308
	8	0.72449	0.72449

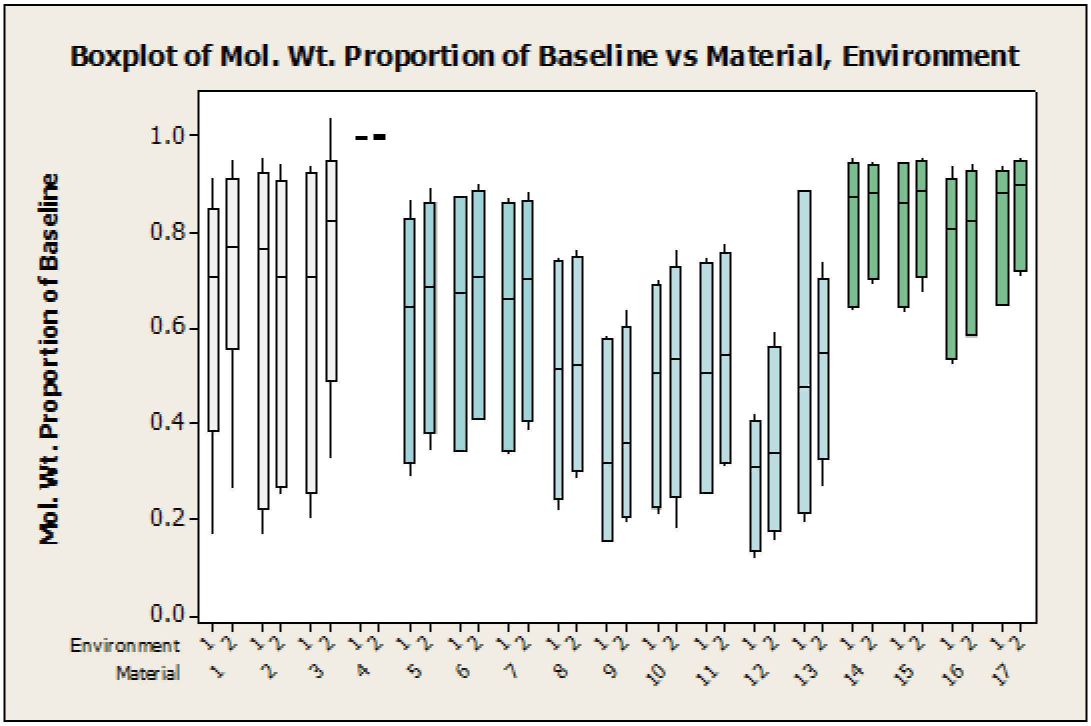

Figure 57: Boxplot of the proportion of molecular weight at baseline by material and degradation environment

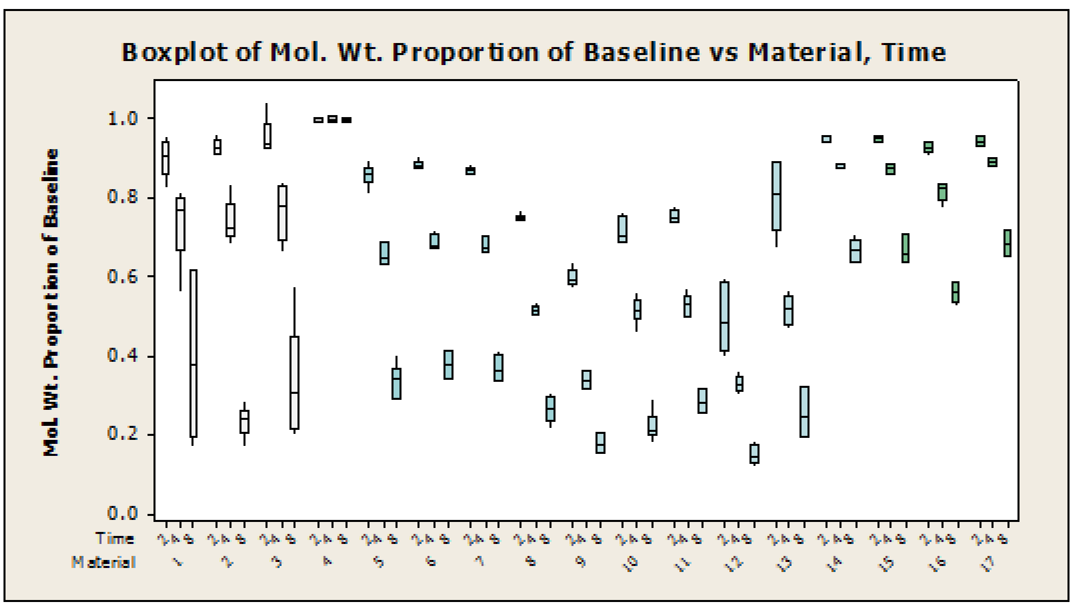

Figure 58: Boxplot of the proportion of molecular weight at baseline by material and degradation time

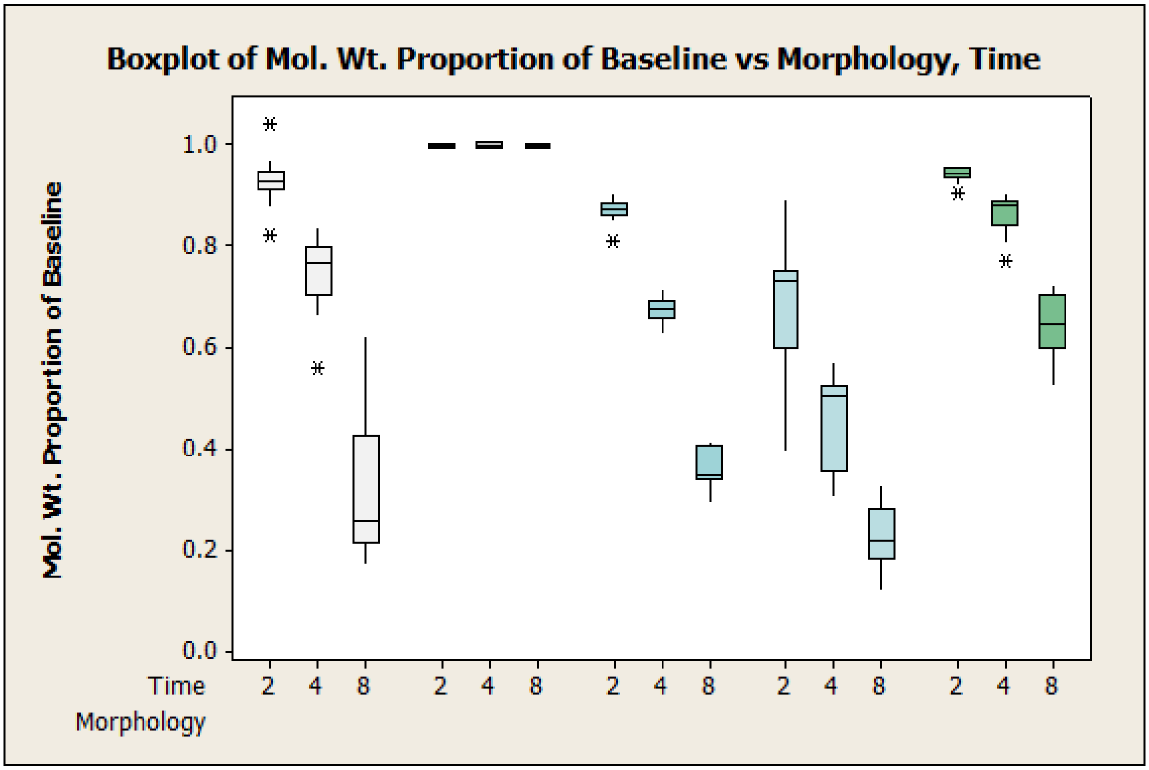

Figure 59: Boxplot of the proportion of molecular weight at baseline by morphology and degradation time

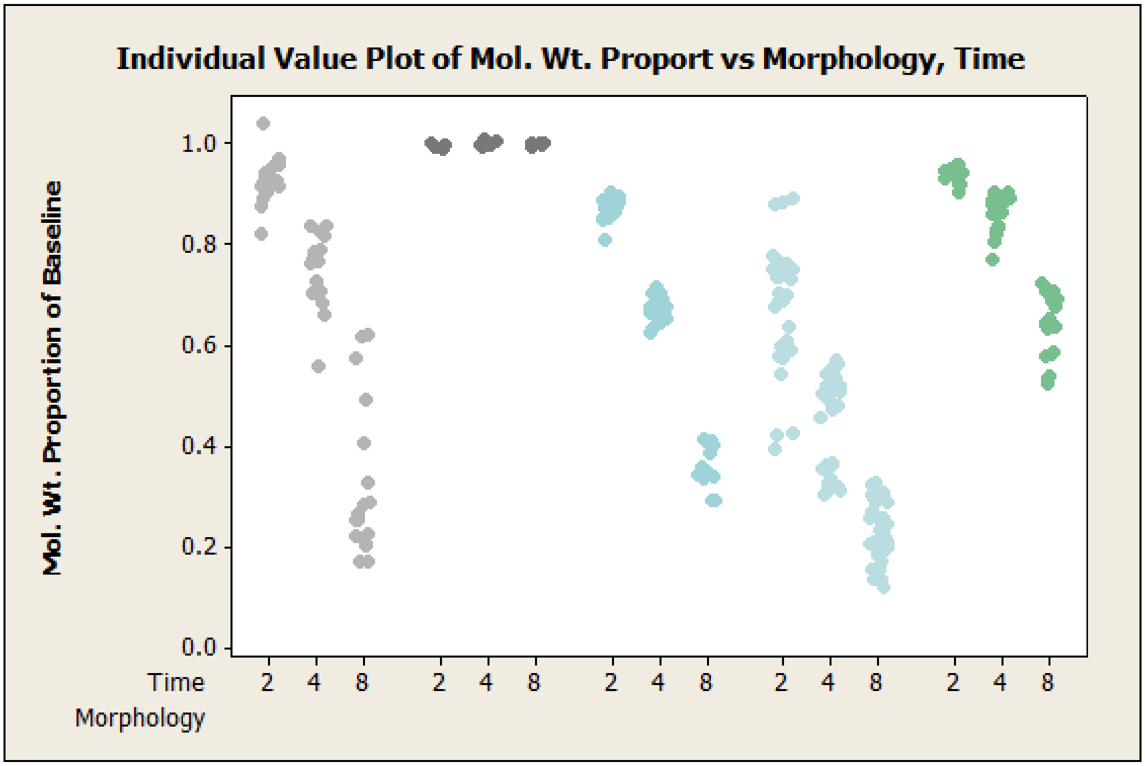

Figure 60:P Individual value plot of the proportion of the baseline molecular weight by morphology and degradation time

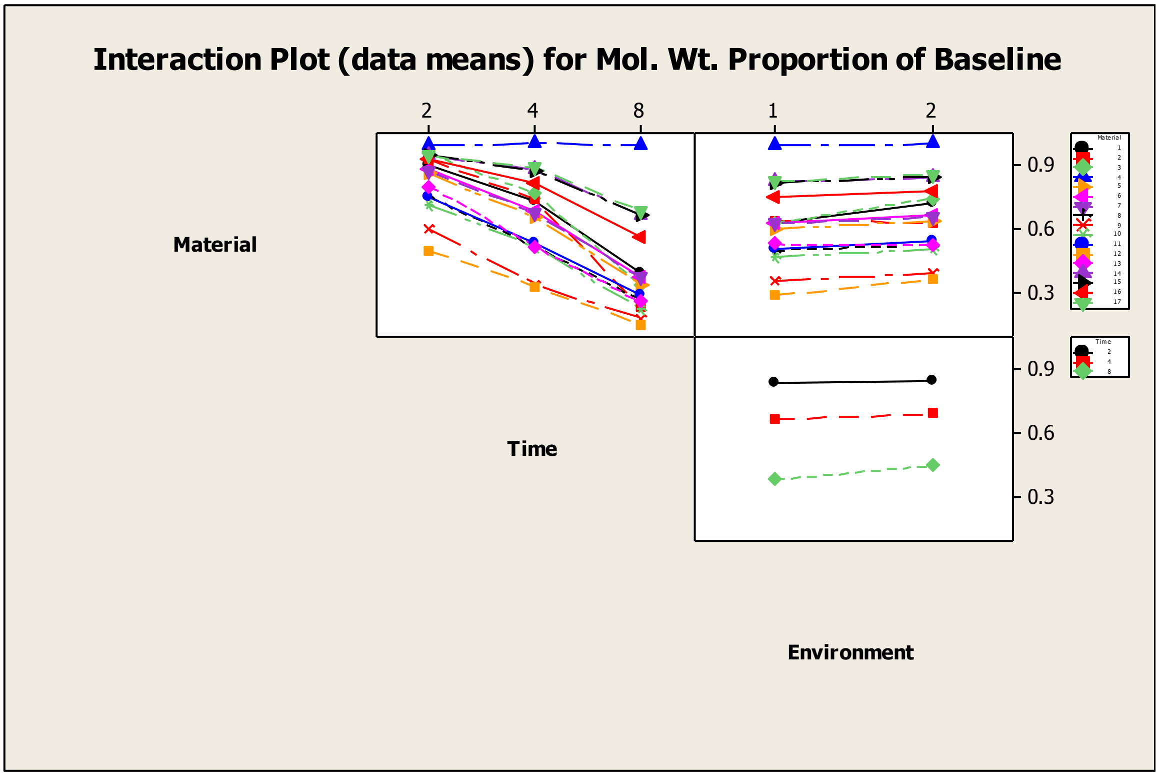

Figure 61: Interaction plot for the proportional molecular weight data, all materials

ANOVA: Mol. Wt. Proport versus Material, Time, Environment

Factor	Type	Levels
Material	fixed	17
Time	fixed	3
Environment	fixed	2

Factor	Values
Material	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Time	2, 4, 8
Environment	1, 2

Analysis of Variance for Mol. Wt. Proportion of Baseline

Source	DF	SS	MS	F	P
Material	16	9.02785	0.56424	304.57	0.000
Time	2	9.51510	4.75755	2568.07	0.000
Environment	1	0.10486	0.10486	56.60	0.000
Material*Time	32	1.42988	0.04468	24.12	0.000
Material*Environment	16	0.07369	0.00461	2.49	0.002
Time*Environment	2	0.03324	0.01662	8.97	0.000
Error	236	0.43721	0.00185		
Total	305	20.62184			

S = 0.0430416   R-Sq = 97.88%   R-Sq(adj) = 97.26%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 102 Q[2]
3	Environment		7	(7) + 153 Q[3]
4	Material*Time		7	(7) + 6 Q[4]
5	Material*Environment		7	(7) + 9 Q[5]
6	Time*Environment		7	(7) + 51 Q[6]
7	Error	0.00185		(7)

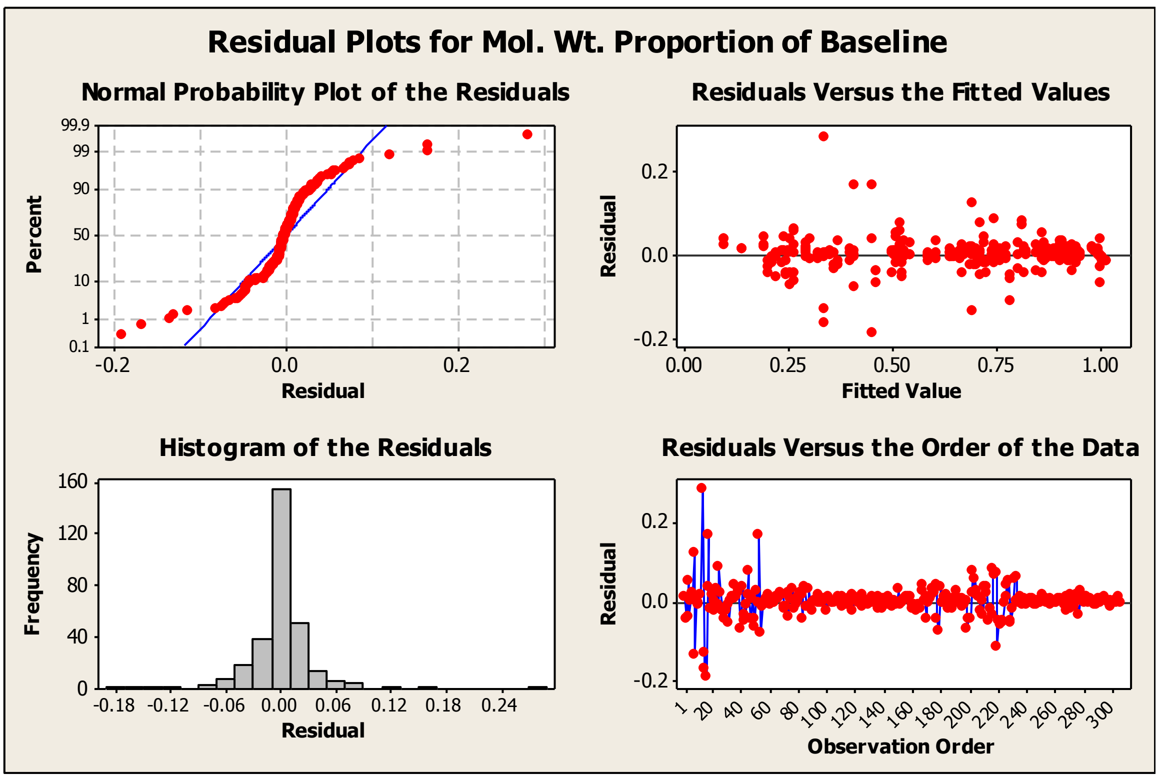

Figure 62: Residual plots for proportional molecular weight data, all materials

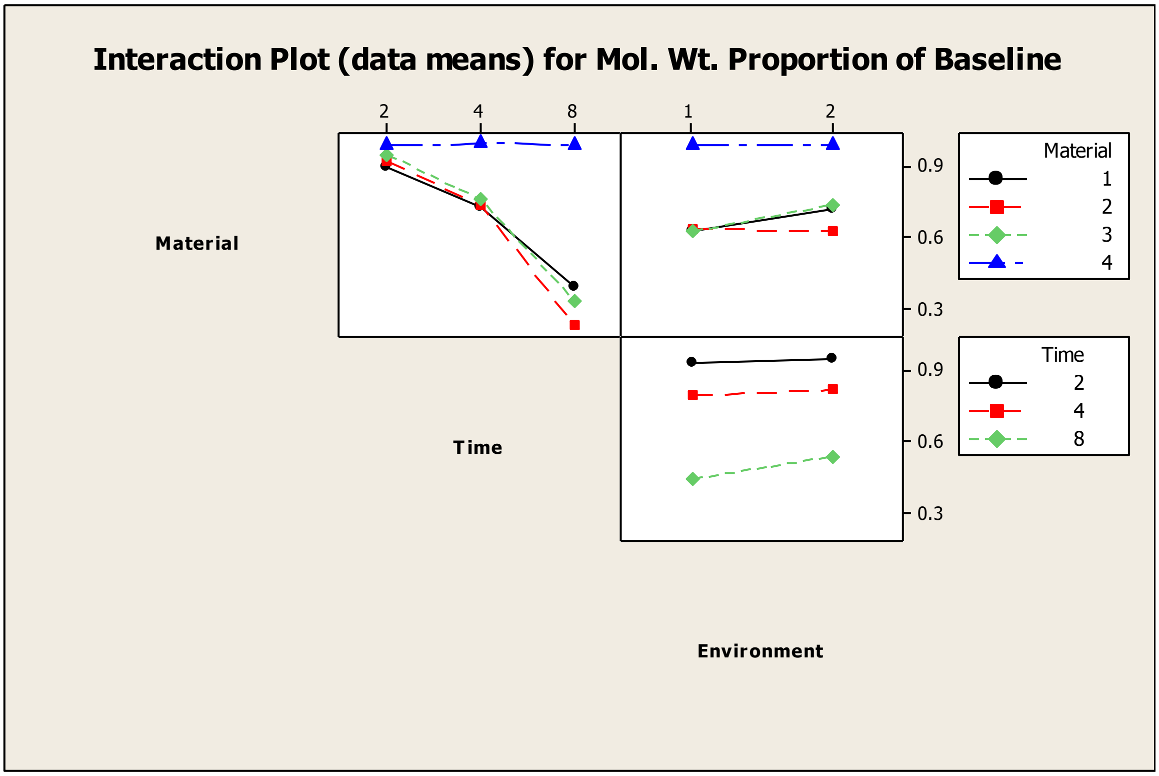

Figure 63: Interaction plot for the proportional molecular weight data, PLLA materials 1-4

ANOVA: Mol. Wt. Proport versus Material, Time, Environment

Factor	Type	Levels	Values
Material	fixed	4	1, 2, 3, 4
Time	fixed	3	2, 4, 8
Environment	fixed	2	1, 2

Analysis of Variance for Mol. Wt. Proportion of Baseline

Source	DF	SS	MS	F	P
Material	3	1.52978	0.50993	89.60	0.000
Time	2	2.60473	1.30237	228.84	0.000
Environment	1	0.04326	0.04326	7.60	0.008
Material*Time	6	0.93721	0.15620	27.45	0.000
Material*Environment	3	0.05285	0.01762	3.10	0.034
Time*Environment	2	0.02035	0.01018	1.79	0.177
Error	54	0.30732	0.00569		
Total	71	5.49550			

S = 0.0754400   R-Sq = 94.41%   R-Sq(adj) = 92.65%

Expected Mean
Square for
Each Term

	Source	Variance component	Error term	(using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 24 Q[2]
3	Environment		7	(7) + 36 Q[3]
4	Material*Time		7	(7) + 6 Q[4]
5	Material*Environment		7	(7) + 9 Q[5]
6	Time*Environment		7	(7) + 12 Q[6]
7	Error	0.00569		(7)

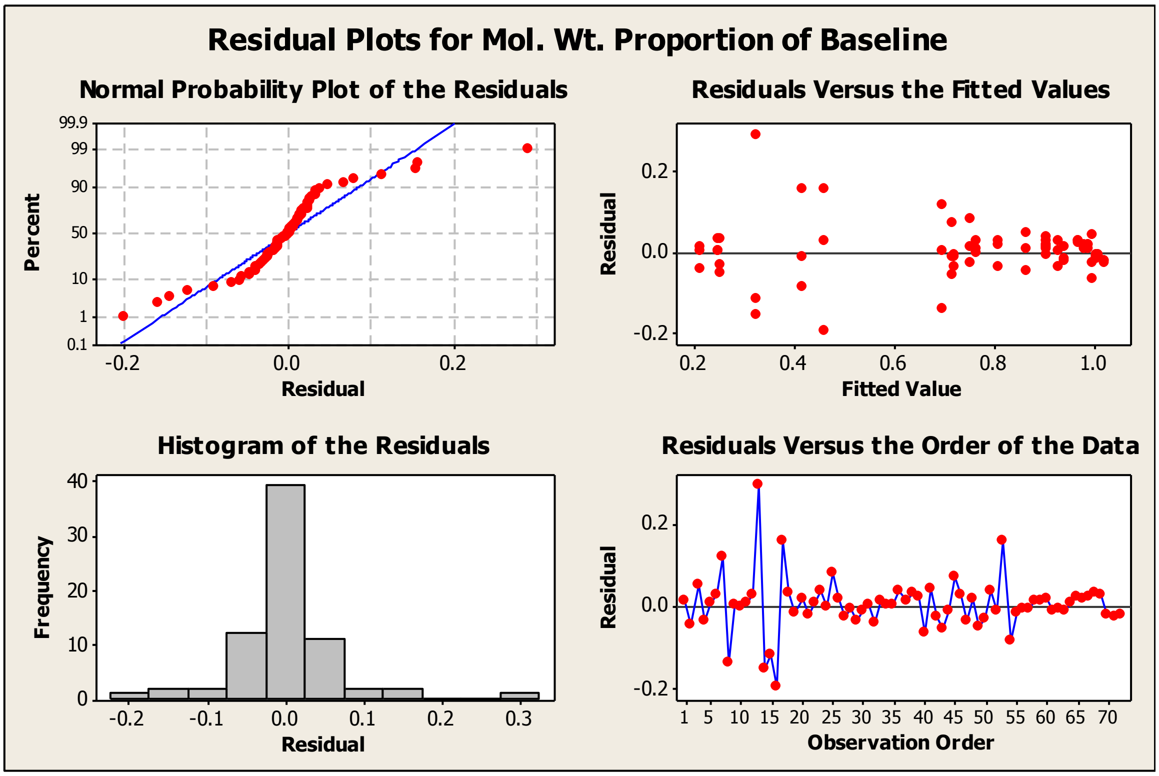

Figure 64: Residual plots for the proportional molecular weight data, PLLA material 1-4

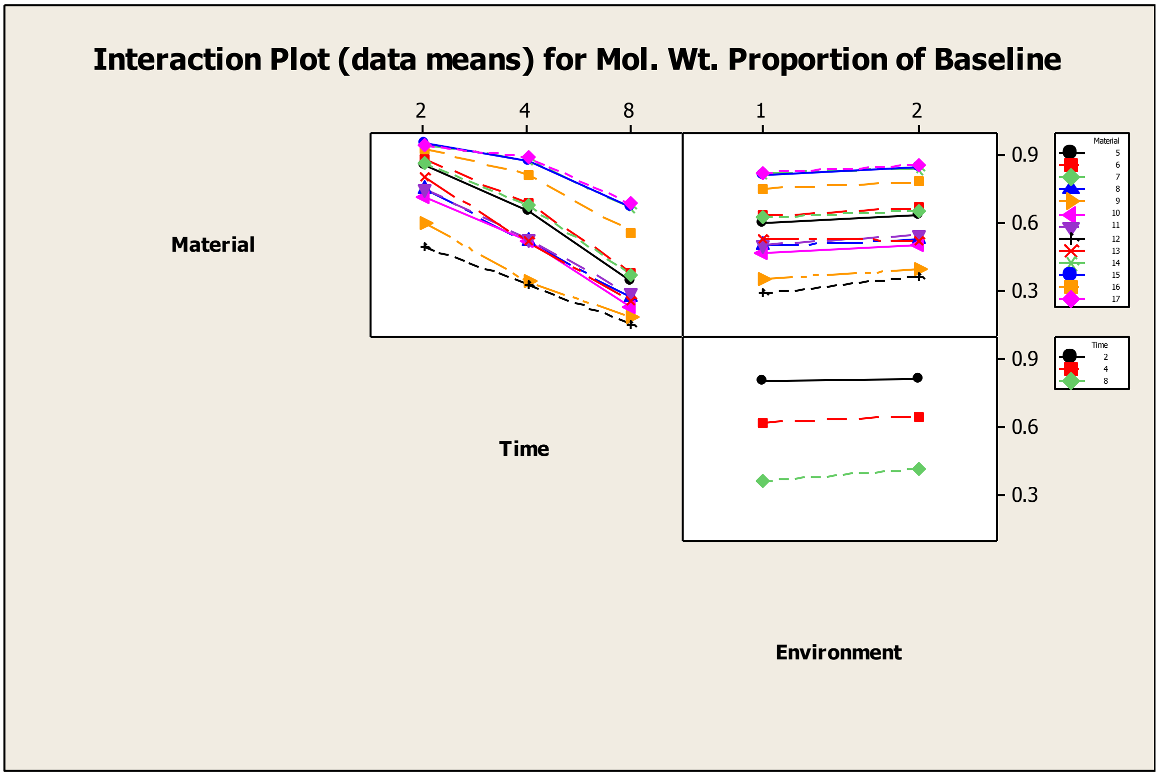

Figure 65: Interaction plots for the proportional molecular weight data, PLLA/PCL material 5-17

ANOVA: Mol. Wt. Proport versus Material, Time, Environment

Factor	Type	Levels	Values
Material	fixed	13	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Time	fixed	3	2, 4, 8
Environment	fixed	2	1, 2

Analysis of Variance for Mol. Wt. Proportion of Baseline

Source	DF	SS	MS	F	P
Material	12	6.42474	0.53539	769.00	0.000
Time	2	6.95819	3.47910	4997.09	0.000
Environment	1	0.06499	0.06499	93.35	0.000
Material*Time	24	0.44485	0.01854	26.62	0.000
Material*Environment	12	0.01746	0.00145	2.09	0.020
Time*Environment	2	0.01745	0.00872	12.53	0.000
Error	180	0.12532	0.00070		
Total	233	14.05300			

S = 0.0263861   R-Sq = 99.11%   R-Sq(adj) = 98.85%

Expected Mean
Square for
Each Term

	Source	Variance component	Error term	(using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 78 Q[2]
3	Environment		7	(7) + 117 Q[3]
4	Material*Time		7	(7) + 6 Q[4]
5	Material*Environment		7	(7) + 9 Q[5]
6	Time*Environment		7	(7) + 39 Q[6]
7	Error	0.00070		(7)

Residual Plots for Mol. Wt. Proportion of Baseline

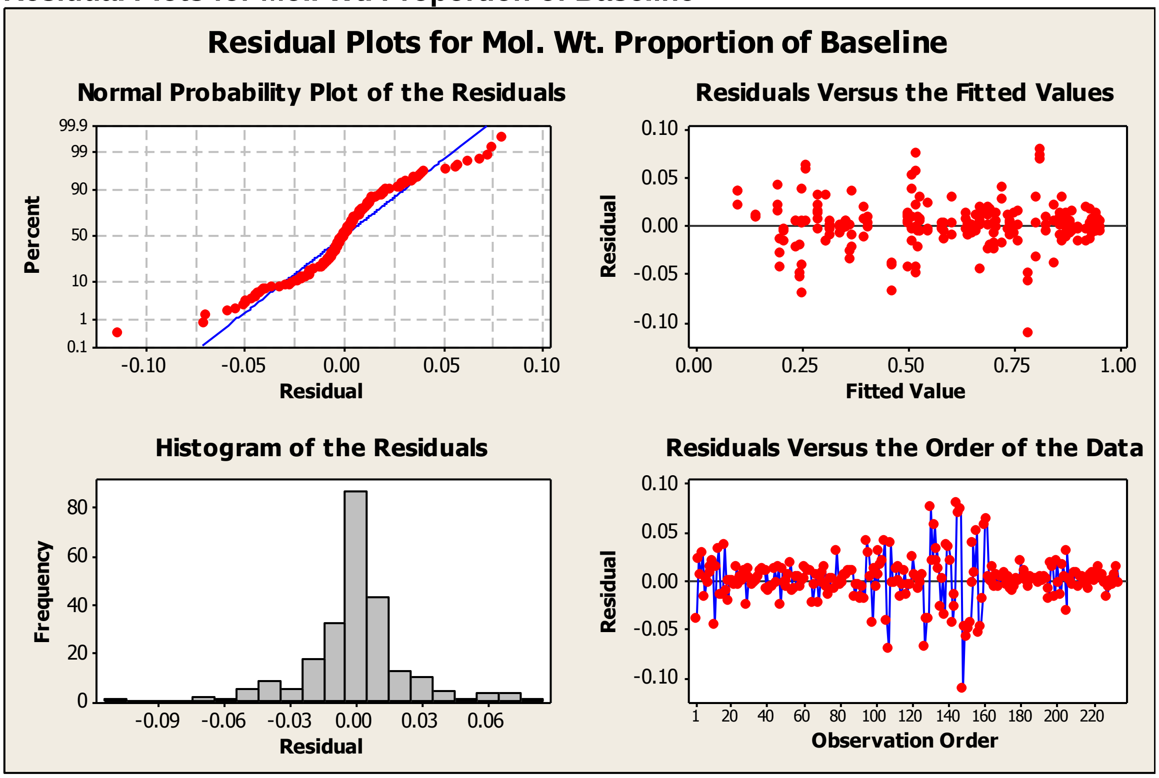

Figure 66: Residual plots for the proportional molecular weight data, PLLA/PCL material 5-17

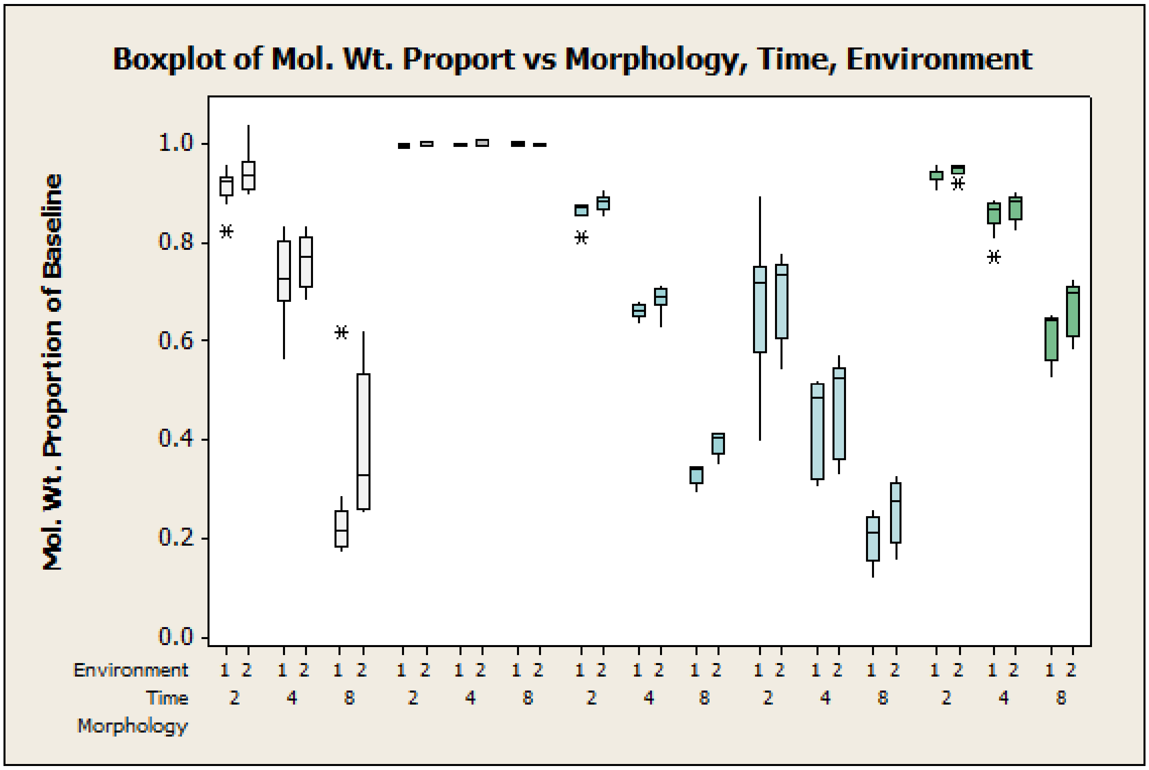

Figure 67: Boxplot of proportional molecular weight by morphology, degradation time and degradation environment

Appendix III: Peak Strain

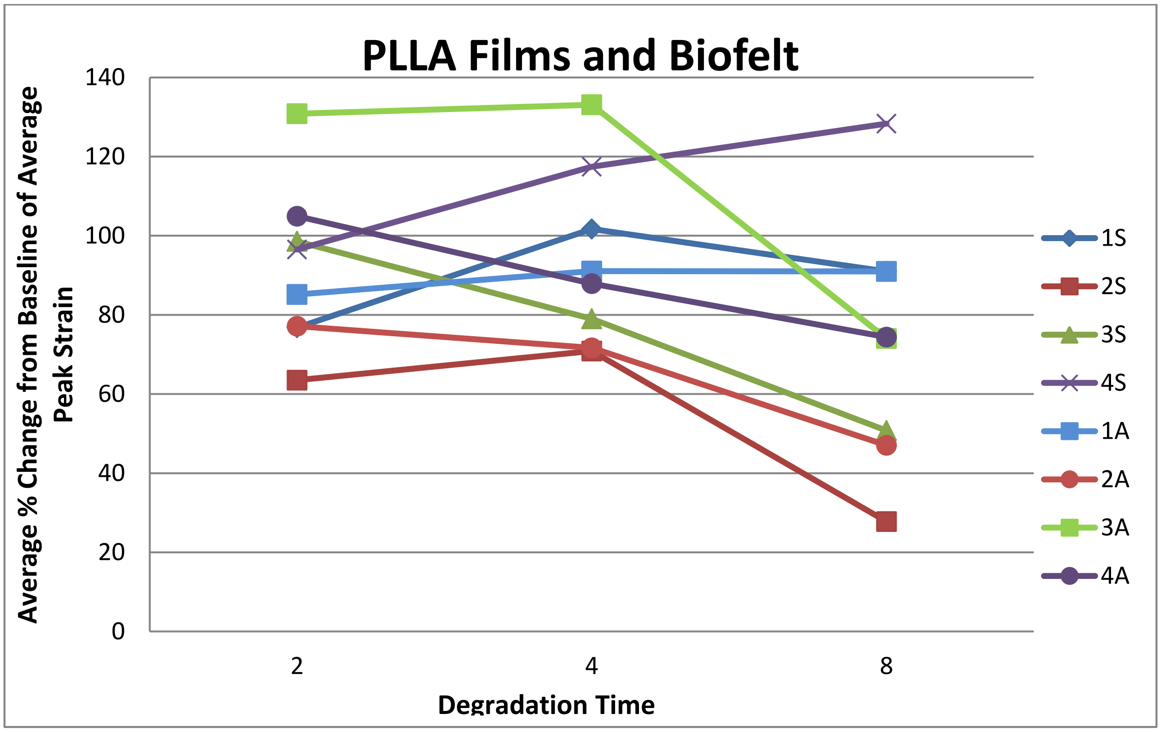

Figure 68: Average percent change from baseline of average peak strain in PLLA films and biofelts (materials 1 through 4). Legend: 1S = material 1 in stagnant environment, 1A = material 1 in agitated environment

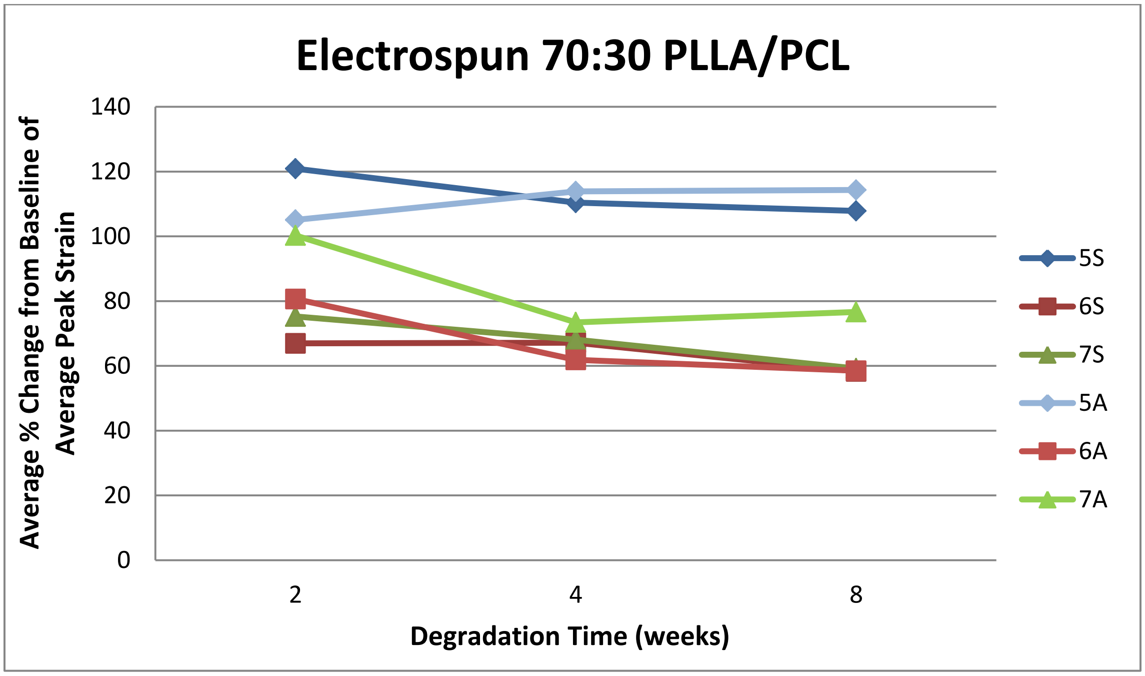

Figure 69: Average percent change from baseline of average peak strain for Electrospun 70:30 PLLA/PCL

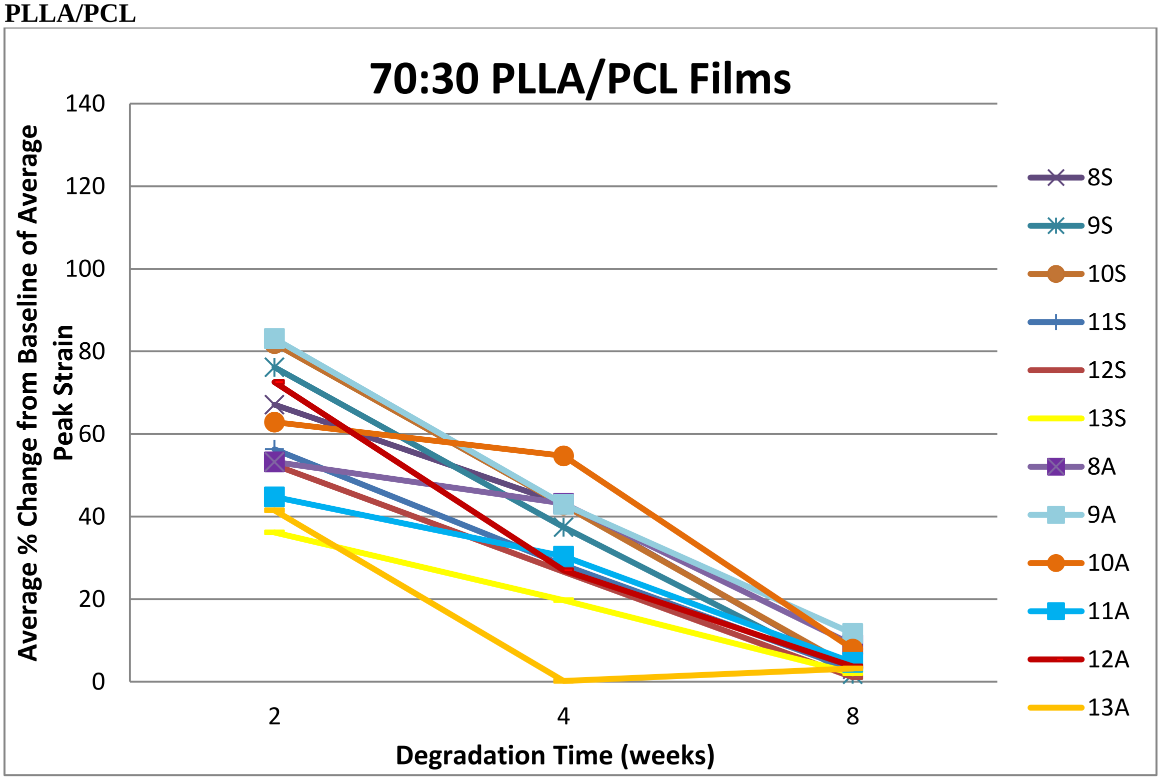

Figure 70: Average percent change from baseline of average peak strain for 70:30 PLLA/PCL films

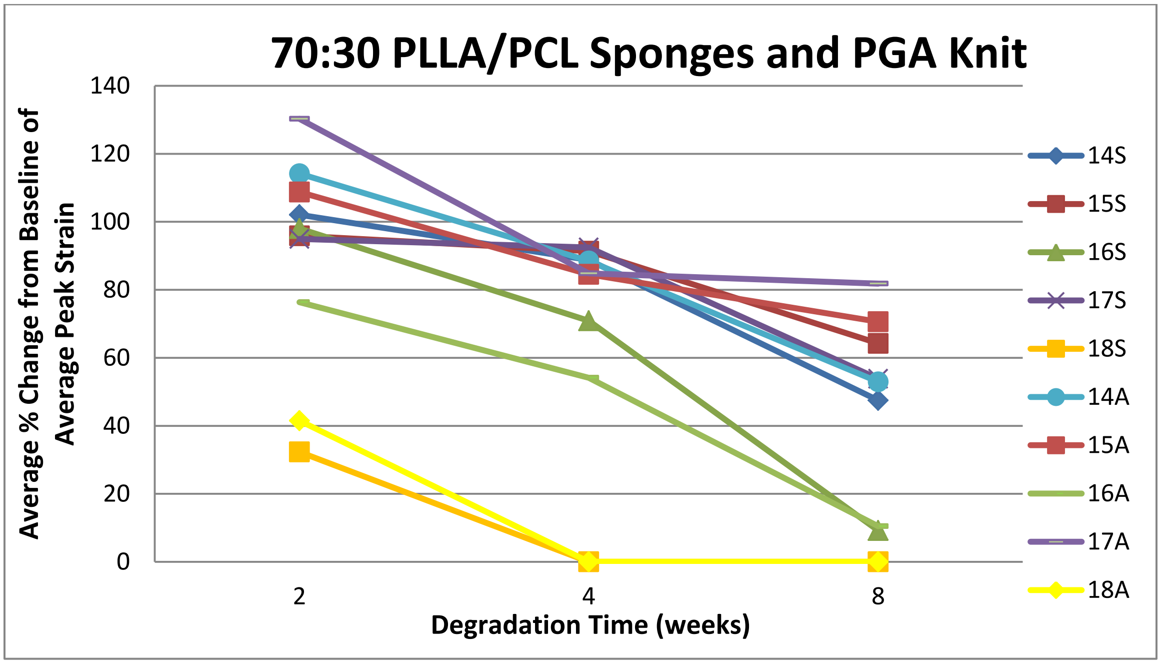

Figure 71: Average percent change from baseline of average peak strain of 70:30 PLLA/PCL sponges (materials 14 through 17) and PGA knit (material 18).

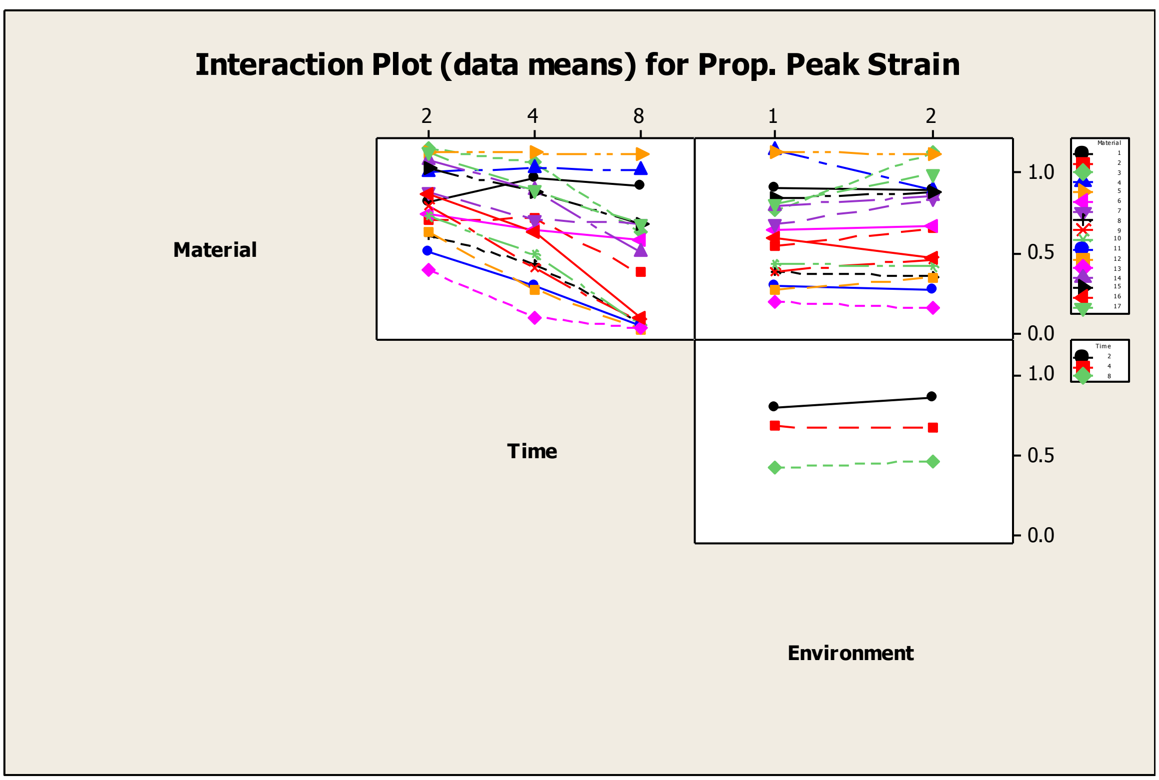

Figure 72: Interaction plots for the proportional peak strain, all materials

ANOVA: Proportion of Peak Strain from Baseline versus Material, Degradation Time and degradation Environment (materials 1-17)

Factor	Type	Levels
Material	fixed	17
Time	fixed	3
Environment	fixed	2

Factor	Values
Material	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Time	2, 4, 8
Environment	1, 2

Analysis of Variance for Prop. Peak Strain

Source	DF	SS	MS	F	P
Material	16	24.02588	1.50162	50.40	0.000
Time	2	7.87364	3.93682	132.12	0.000
Environment	1	0.09438	0.09438	3.17	0.076
Material*Time	32	3.77511	0.11797	3.96	0.000
Material*Environment	16	1.27755	0.07985	2.68	0.001
Time*Environment	2	0.07417	0.03709	1.24	0.290
Error	236	7.03192	0.02980		
Total	305	44.15266			

S = 0.172616   R-Sq = 84.07%   R-Sq(adj) = 79.42%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 102 Q[2]
3	Environment		7	(7) + 153 Q[3]
4	Material*Time		7	(7) + 6 Q[4]
5	Material*Environment		7	(7) + 9 Q[5]
6	Time*Environment		7	(7) + 51 Q[6]
7	Error	0.02980		(7)

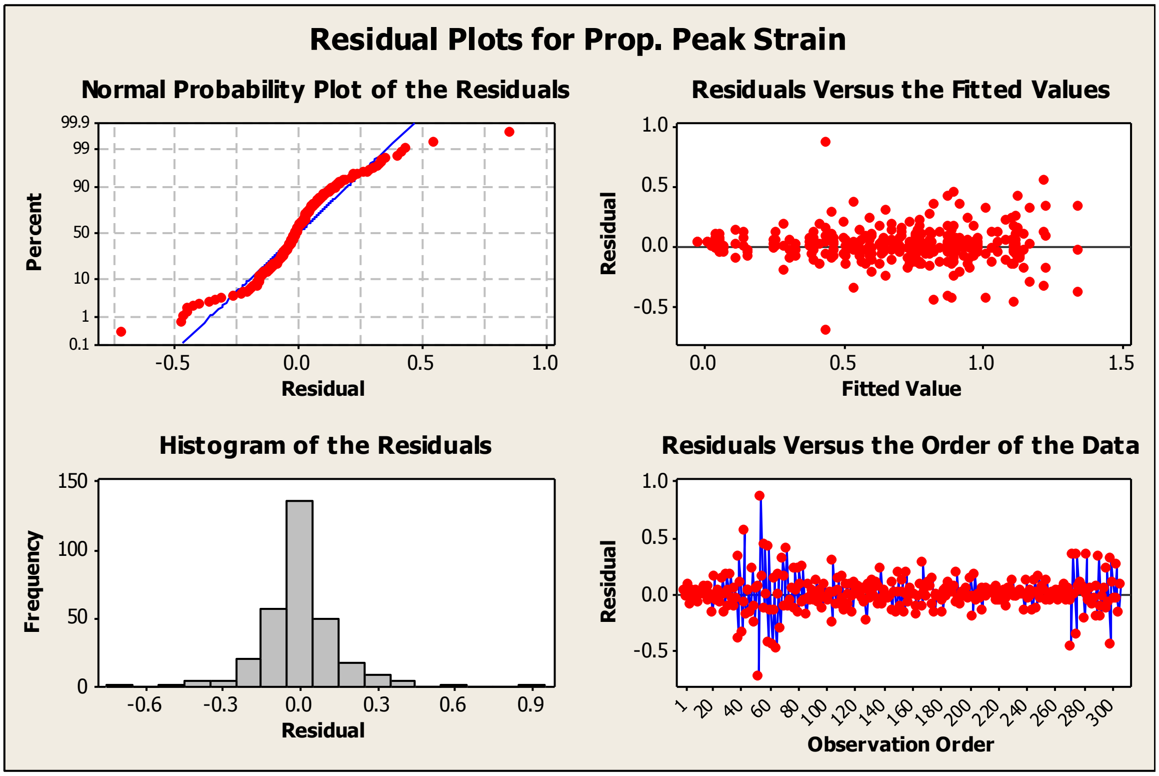

Figure 73: Residual plots for the proportional peak strain, all materials

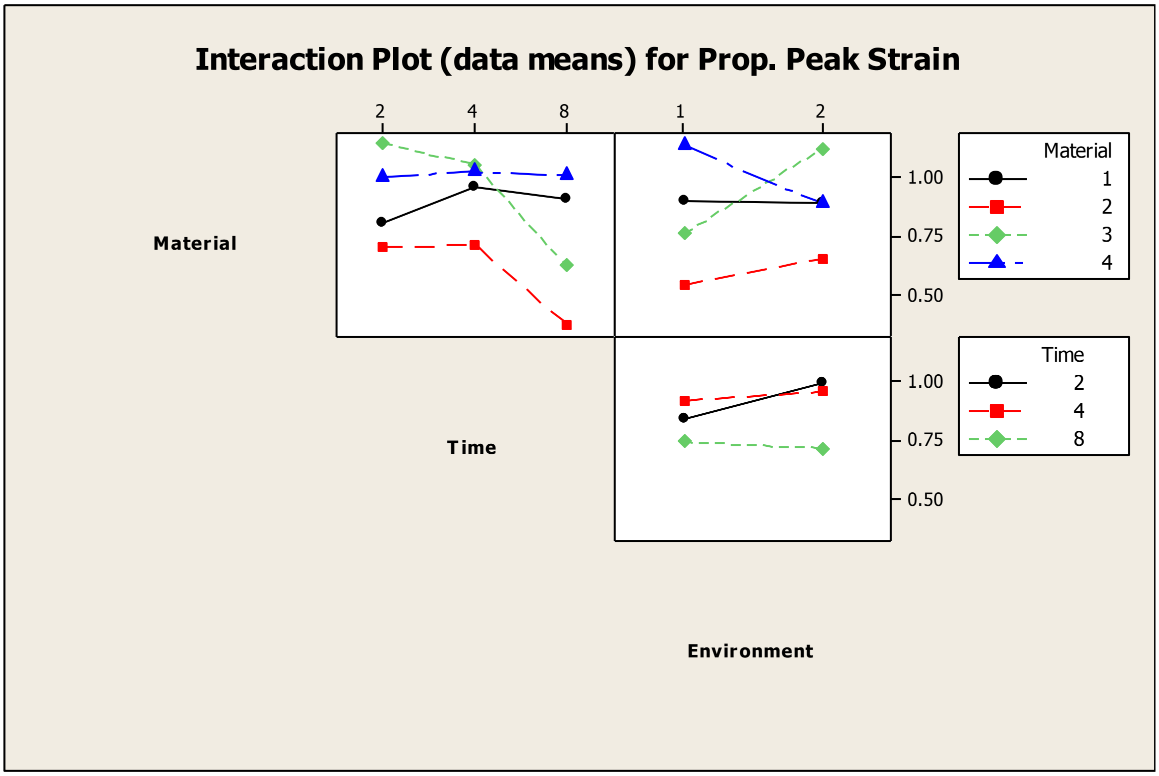

Figure 74: Interaction plot for proportional peak strain, materials 1-4

ANOVA: Proportion of Peak Strain from Baseline versus Material, Degradation Time and Degradation Environment (materials 1-4)

Factor	Type	Levels	Values
Material	fixed	4	1, 2, 3, 4
Time	fixed	3	2, 4, 8
Environment	fixed	2	1, 2

Analysis of Variance for Prop. Peak Strain

Source	DF	SS	MS	F	P
Material	3	1.83268	0.61089	8.71	0.000
Time	2	0.63794	0.31897	4.55	0.015
Environment	1	0.05416	0.05416	0.77	0.383
Material*Time	6	0.82652	0.13775	1.96	0.087
Material*Environment	3	0.88516	0.29505	4.21	0.010
Time*Environment	2	0.10588	0.05294	0.76	0.475
Error	54	3.78613	0.07011		
Total	71	8.12847			

S = 0.264790   R-Sq = 53.42%   R-Sq(adj) = 38.76%

Expected Mean
Square for

	Source	Variance component	Error term	Each Term (using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 24 Q[2]
3	Environment		7	(7) + 36 Q[3]
4	Material*Time		7	(7) + 6 Q[4]
5	Material*Environment		7	(7) + 9 Q[5]
6	Time*Environment		7	(7) + 12 Q[6]
7	Error	0.07011		(7)

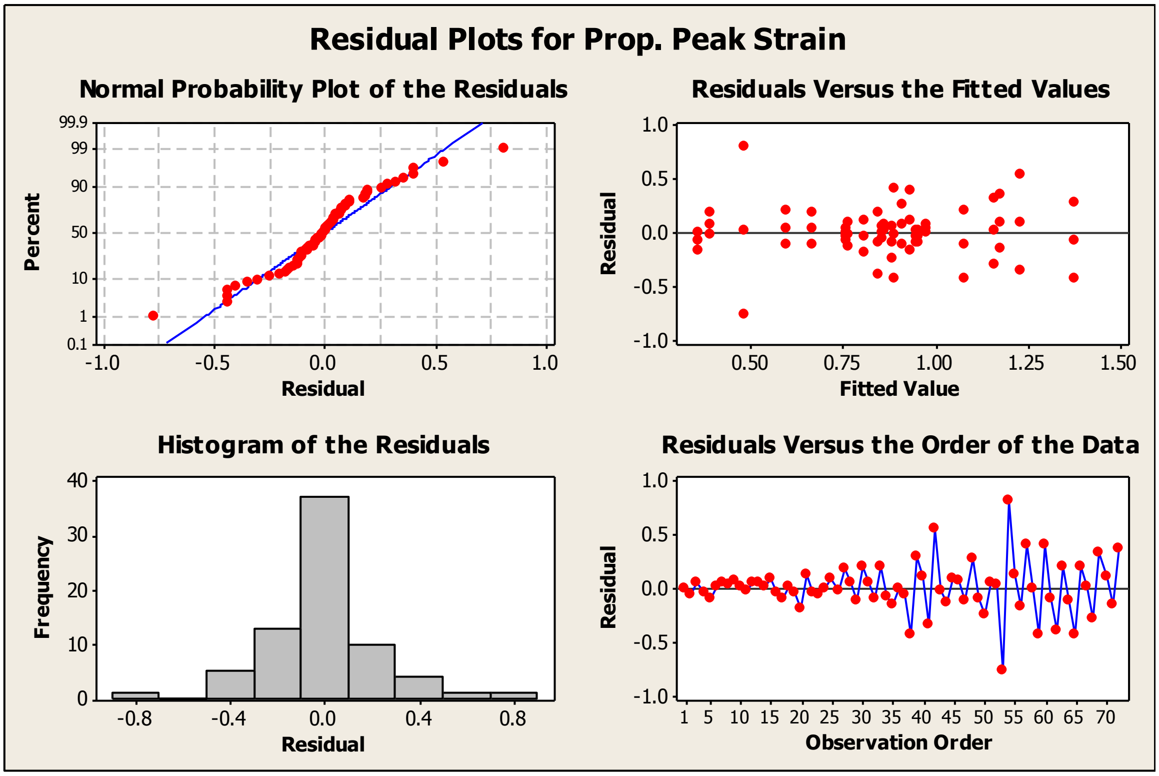

Figure 75: Residual plots for proportional peak strain, materials 1-4

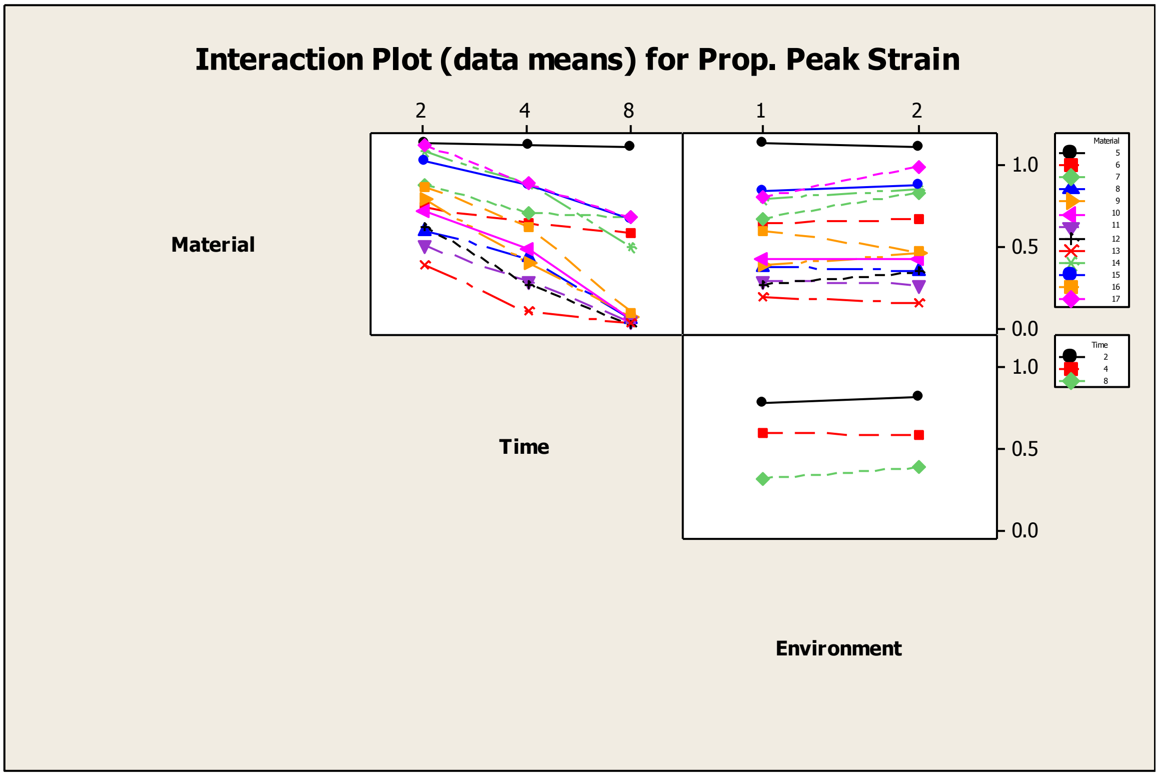

Figure 76: Interaction plot for proportional peak strain, materials 5-17

ANOVA: Proportion of Peak Strain from Baseline versus Material, Degradation Time and Degradation Environment (materials 5-17)

Factor	Type	Levels	Values
Material	fixed	13	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
Time	fixed	3	2, 4, 8
Environment	fixed	2	1, 2

Analysis of Variance for Prop. Peak Strain

Source	DF	SS	MS	F	P
Material	12	17.95527	1.49627	86.03	0.000
Time	2	8.01680	4.00840	230.48	0.000
Environment	1	0.04938	0.04938	2.84	0.094
Material*Time	24	2.16749	0.09031	5.19	0.000
Material*Environment	12	0.38323	0.03194	1.84	0.045
Time*Environment	2	0.08358	0.04179	2.40	0.093
Error	180	3.13050	0.01739		
Total	233	31.78626			

S = 0.131878   R-Sq = 90.15%   R-Sq(adj) = 87.25%

Expected Mean
Square for

	Source	Variance component	Error term	Expected Mean Square for Each Term (using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 78 Q[2]
3	Environment		7	(7) + 117 Q[3]
4	Material*Time		7	(7) + 6 Q[4]
5	Material*Environment		7	(7) + 9 Q[5]
6	Time*Environment		7	(7) + 39 Q[6]
7	Error	0.01739		(7)

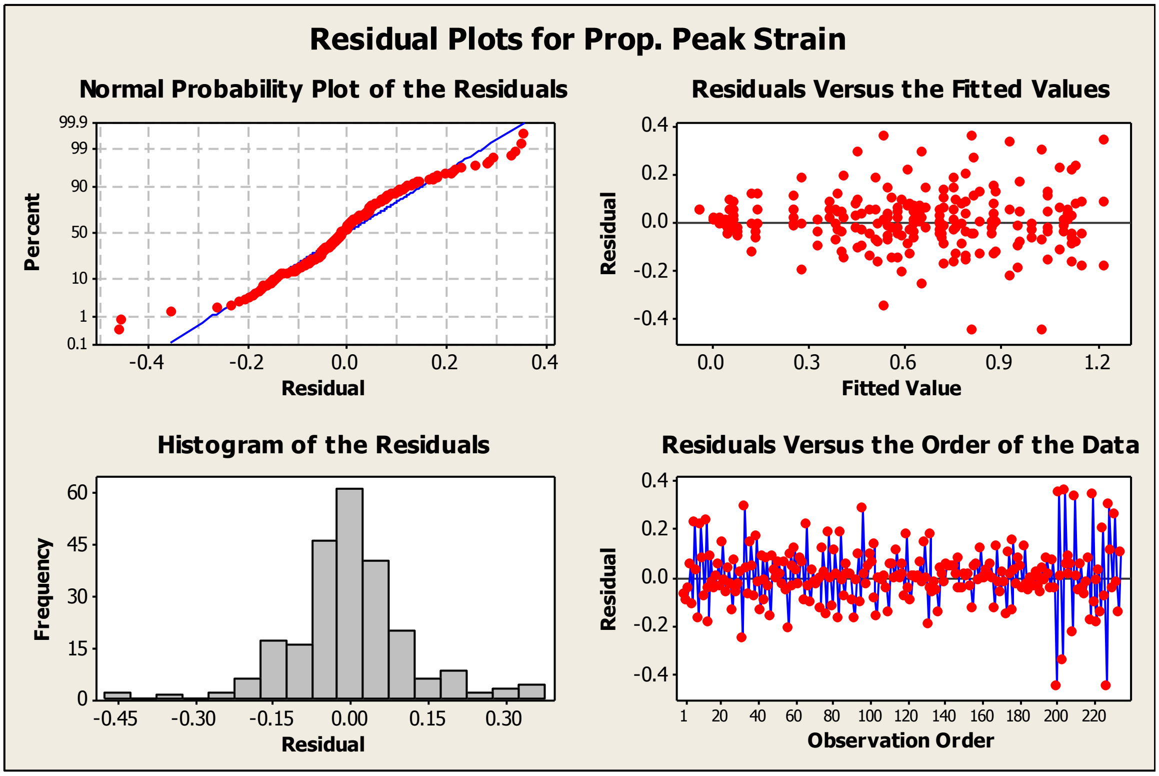

Figure 77: Residual plots for proportional peak strain, materials 5-17

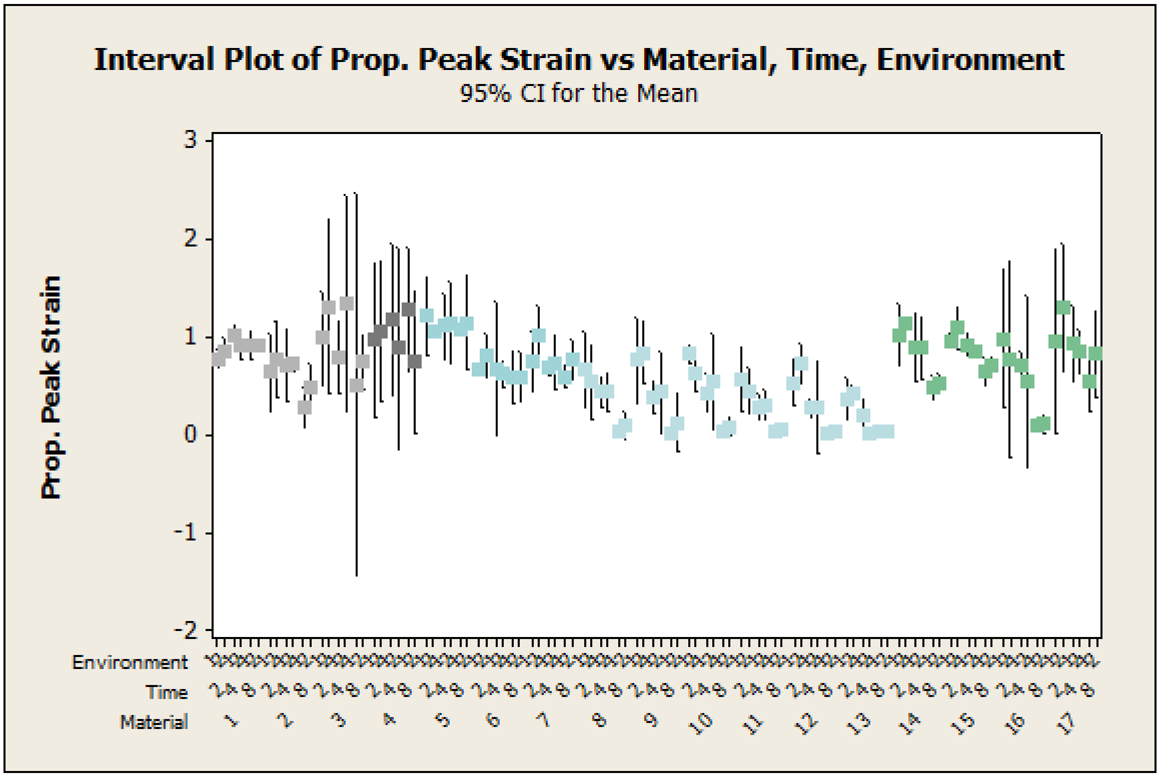

Figure 78: Interval plot of proportional peak strain vs material, degradation time and degradation environment

Individual Material ANOVAs of Proportional Peak Strain by Degradation Time:

One-way ANOVA: Prop. Peak Strain versus Time for Material 1

```
Source  DF       SS       MS      F      P
Time     2  0.07334  0.03667  10.18  0.002
Error   15  0.05404  0.00360
Total   17  0.12739

S = 0.06002   R-Sq = 57.58%   R-Sq(adj) = 51.92%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --+---------+---------+---------+-------
2      6  0.8097  0.0628  (-------*------)
4      6  0.9638  0.0729                      (-------*------)
8      6  0.9097  0.0395              (-------*------)
                          --+---------+---------+---------+-------
                          0.770     0.840     0.910     0.980

Pooled StDev = 0.0600


Tukey 95% Simultaneous Confidence Intervals
```

```
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower    Center     Upper  ----+---------+---------+---------+-----
4      0.06415   0.15409   0.24402                   (--------*--------)
8      0.01012   0.10005   0.18998              (--------*--------)
                                    ----+---------+---------+---------+-----
                                     -0.10      0.00      0.10      0.20


Time = 4 subtracted from:

Time      Lower    Center     Upper  ----+---------+---------+---------+-----
8      -0.14396  -0.05403  0.03590  (--------*--------)
                                      ----+---------+---------+---------+-----
                                       -0.10      0.00      0.10      0.20
```

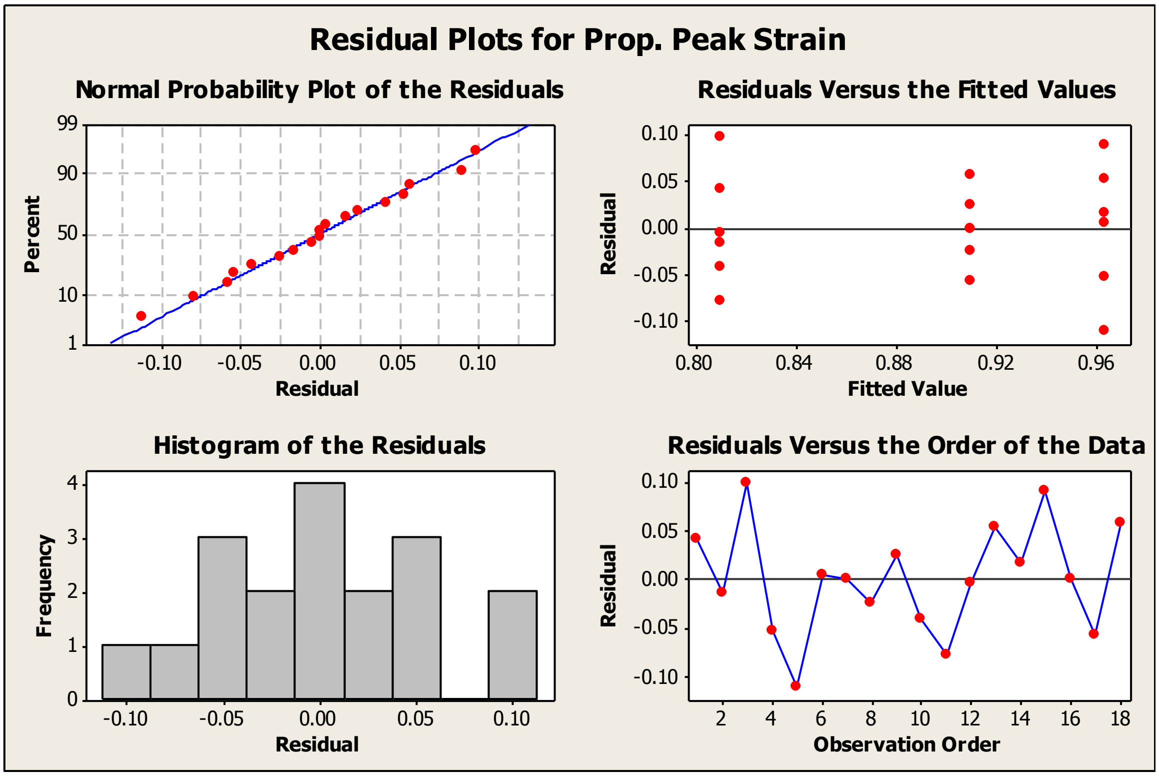

Figure 79: Residual plots for proportional peak strain, material 1

One-way ANOVA: Prop. Peak Strain versus Time for Material 2

```
Source  DF      SS      MS      F      P
Time     2  0.4464  0.2232  12.66  0.001
Error   15  0.2645  0.0176
Total   17  0.7108
```

```
S = 0.1328   R-Sq = 62.79%   R-Sq(adj) = 57.83%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ---+---------+---------+---------+------
2      6  0.7033  0.1606                      (-------*-------)
4      6  0.7126  0.0957                       (-------*------)
8      6  0.3740  0.1340  (-------*-------)
                          ---+---------+---------+---------+------
                           0.30      0.45      0.60      0.75

Pooled StDev = 0.1328


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper  --------+---------+---------+---------+-
4     -0.1896   0.0093   0.2083             (-----*------)
8     -0.5282  -0.3293  -0.1303  (------*------)
                                 --------+---------+---------+---------+-
                                      -0.30      0.00      0.30      0.60


Time = 4 subtracted from:

Time    Lower   Center    Upper  --------+---------+---------+---------+-
8     -0.5376  -0.3386  -0.1397  (------*-----)
                                 --------+---------+---------+---------+-
                                      -0.30      0.00      0.30      0.60
```

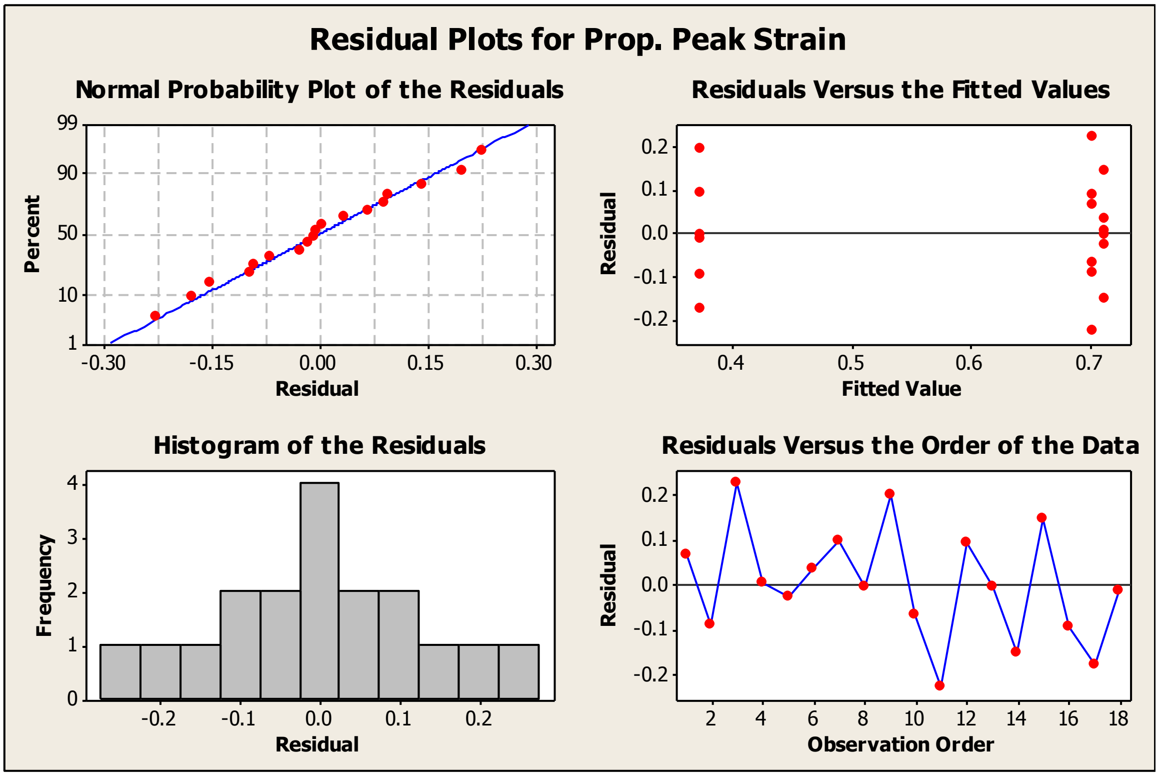

Figure 80: Residual plots for proportional peak strain, material 2

One-way ANOVA: Prop. Peak Strain versus Time for Material 3

```
Source  DF     SS     MS     F      P
Time     2  0.944  0.472  2.60  0.107
Error   15  2.719  0.181
Total   17  3.663

S = 0.4258   R-Sq = 25.76%   R-Sq(adj) = 15.86%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ---+---------+---------+---------+------
2      6  1.1470  0.3127                (----------*---------)
4      6  1.0605  0.4192              (---------*----------)
8      6  0.6239  0.5200  (----------*---------)
                          ---+---------+---------+---------+------
                           0.35      0.70      1.05      1.40

Pooled StDev = 0.4258


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower    Center    Upper  ---------+---------+---------+---------+
4      -0.7245   -0.0866   0.5514          (----------*---------)
8      -1.1611   -0.5231   0.1148  (---------*----------)
                                   ---------+---------+---------+---------+
                                        -0.60      0.00      0.60      1.20


Time = 4 subtracted from:

Time     Lower    Center    Upper  ---------+---------+---------+---------+
8      -1.0745   -0.4366   0.2014   (----------*---------)
                                   ---------+---------+---------+---------+
                                        -0.60      0.00      0.60      1.20
```

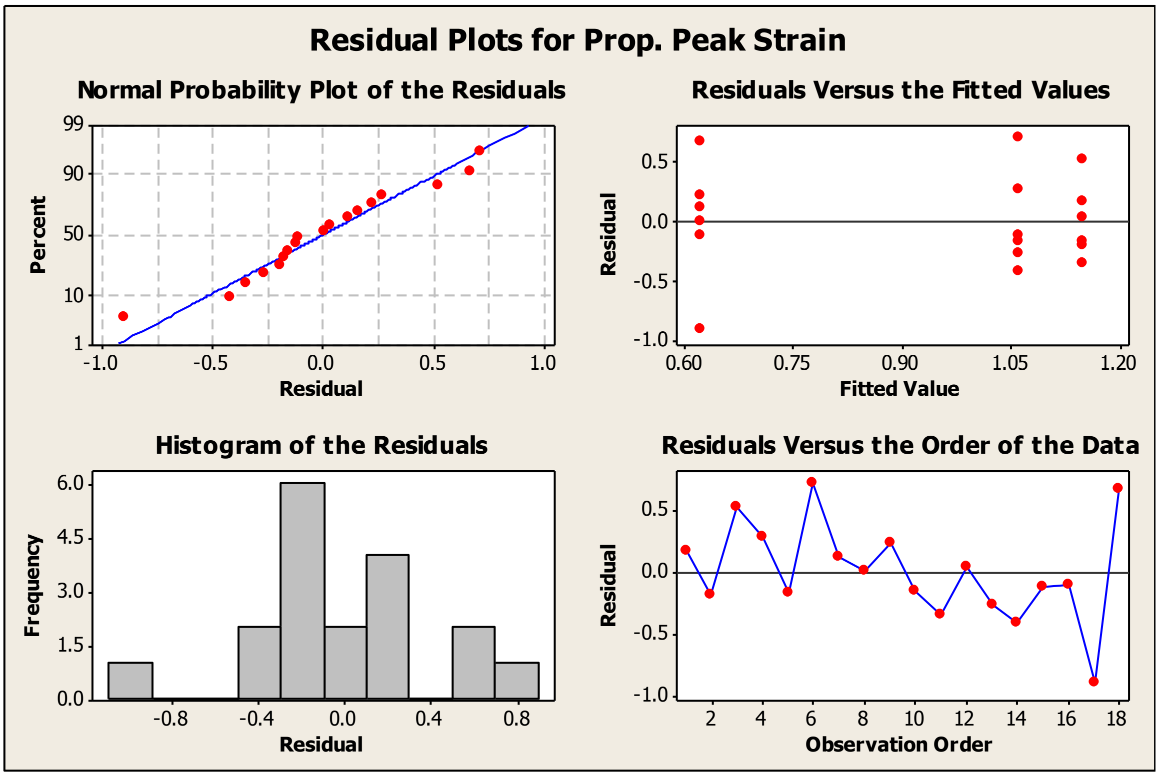

Figure 81: Residual plots for proportional peak strain, material 3

One-way ANOVA: Prop. Peak Strain versus Time for Material 4

```
Source  DF     SS     MS     F      P
Time     2  0.001  0.001  0.00  0.995
Error   15  1.793  0.120
Total   17  1.795

S = 0.3458   R-Sq = 0.07%   R-Sq(adj) = 0.00%


                          Individual 95% CIs For Mean Based on
```

```
                          Pooled StDev
Level  N    Mean   StDev  ------+---------+---------+---------+---
2      6  1.0073  0.2751  (-------------------*-------------------)
4      6  1.0268  0.3677   (-------------------*-------------------)
8      6  1.0135  0.3844   (------------------*-------------------)
                          ------+---------+---------+---------+---
                              0.80      0.96      1.12      1.28

Pooled StDev = 0.3458


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower  Center   Upper  --------+---------+---------+---------+-
4     -0.4986  0.0195  0.5376   (-----------------*----------------)
8     -0.5119  0.0062  0.5243   (----------------*----------------)
                               --------+---------+---------+---------+-
                                    -0.30      0.00      0.30      0.60


Time = 4 subtracted from:

Time    Lower   Center   Upper  --------+---------+---------+---------+-
8     -0.5314  -0.0133  0.5048  (-----------------*----------------)
                                --------+---------+---------+---------+-
                                     -0.30      0.00      0.30      0.60
```

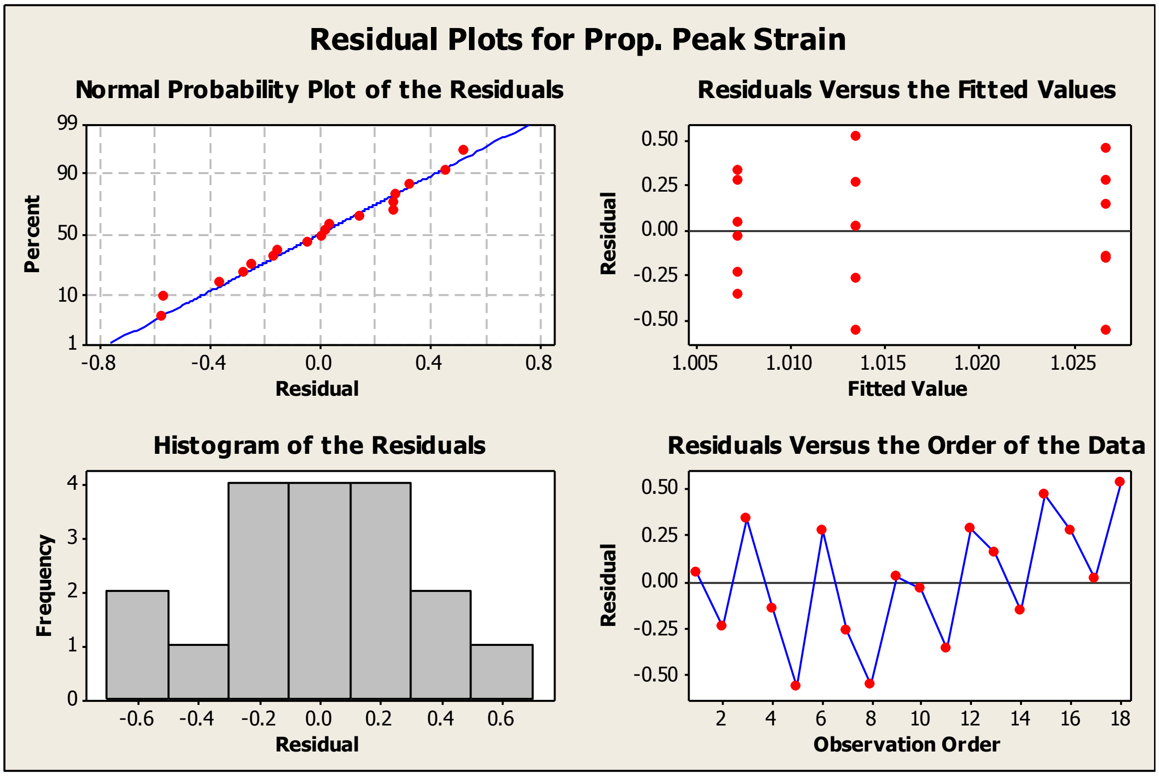

Figure 82: Residual plots for proportional peak strain, material 4

One-way ANOVA: Prop. Peak Strain versus Time for Material 5

```
Source  DF      SS      MS     F      P
Time     2  0.0011  0.0006  0.03  0.969
Error   15  0.2685  0.0179
Total   17  0.2696

S = 0.1338   R-Sq = 0.41%   R-Sq(adj) = 0.00%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --------+---------+---------+---------+-
2      6  1.1301  0.1338     (----------------*----------------)
4      6  1.1218  0.1390    (----------------*----------------)
8      6  1.1109  0.1283  (-----------------*----------------)
                          --------+---------+---------+---------+-
                                1.050     1.120     1.190     1.260

Pooled StDev = 0.1338


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower   Center   Upper  --------+---------+---------+---------+-
4      -0.2088  -0.0084  0.1921   (---------------*----------------)
8      -0.2197  -0.0192  0.1812  (---------------*----------------)
                                 --------+---------+---------+---------+-
                                     -0.12      0.00      0.12      0.24


Time = 4 subtracted from:

Time     Lower   Center   Upper  --------+---------+---------+---------+-
8      -0.2113  -0.0109  0.1896  (----------------*----------------)
                                 --------+---------+---------+---------+-
                                     -0.12      0.00      0.12      0.24
```

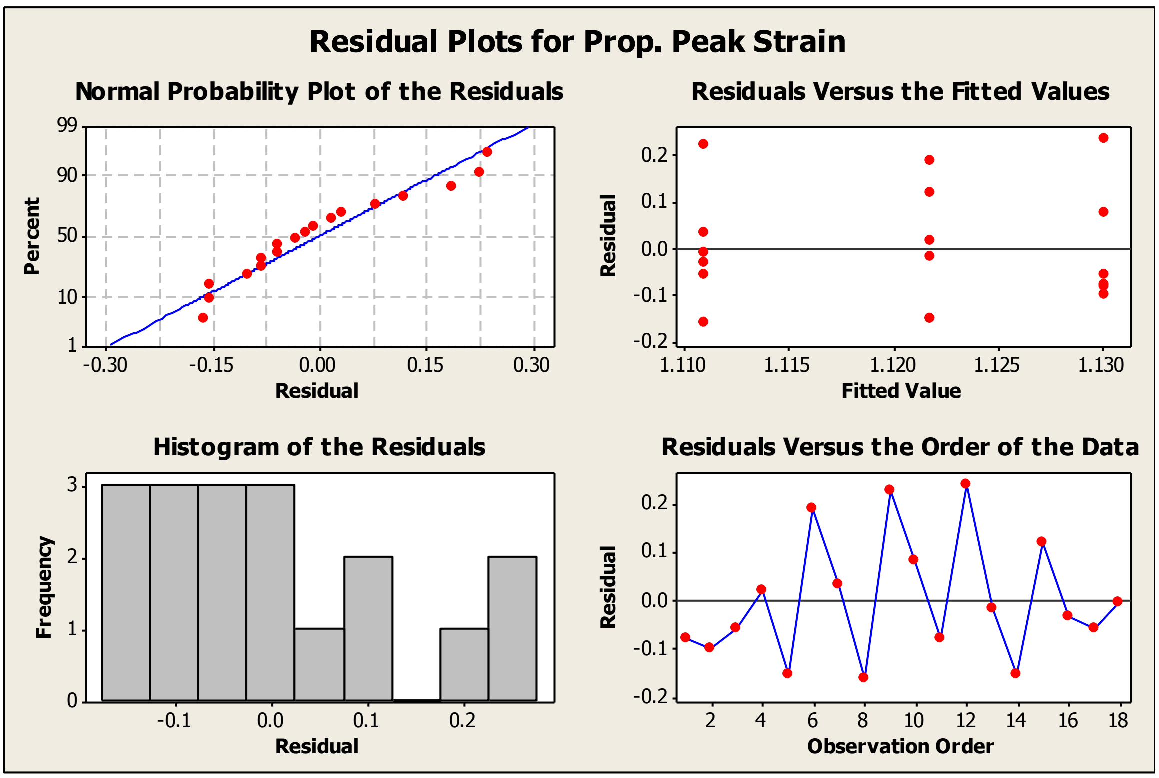

Figure 83: Residual plots for proportional peak strain, material 5

One-way ANOVA: Prop. Peak Strain versus Time for Material 6

```
Source  DF      SS      MS     F      P
Time     2  0.0722  0.0361  2.15  0.151
Error   15  0.2516  0.0168
Total   17  0.3238

S = 0.1295   R-Sq = 22.31%   R-Sq(adj) = 11.95%
```

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ---+---------+---------+---------+------
2      6  0.7382  0.0944                  (----------*----------)
4      6  0.6452  0.1796        (-----------*----------)
8      6  0.5841  0.0957  (----------*-----------)
                          ---+---------+---------+---------+------
                           0.50      0.60      0.70      0.80

Pooled StDev = 0.1295


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center   Upper   --+---------+---------+---------+-------
4     -0.2870  -0.0930  0.1011       (-----------*-----------)
8     -0.3481  -0.1541  0.0400   (-----------*-----------)
                                 --+---------+---------+---------+-------
                                -0.32     -0.16      0.00      0.16


Time = 4 subtracted from:

Time    Lower   Center   Upper   --+---------+---------+---------+-------
8     -0.2551  -0.0611  0.1329         (-----------*-----------)
                                 --+---------+---------+---------+-------
                                -0.32     -0.16      0.00      0.16
```

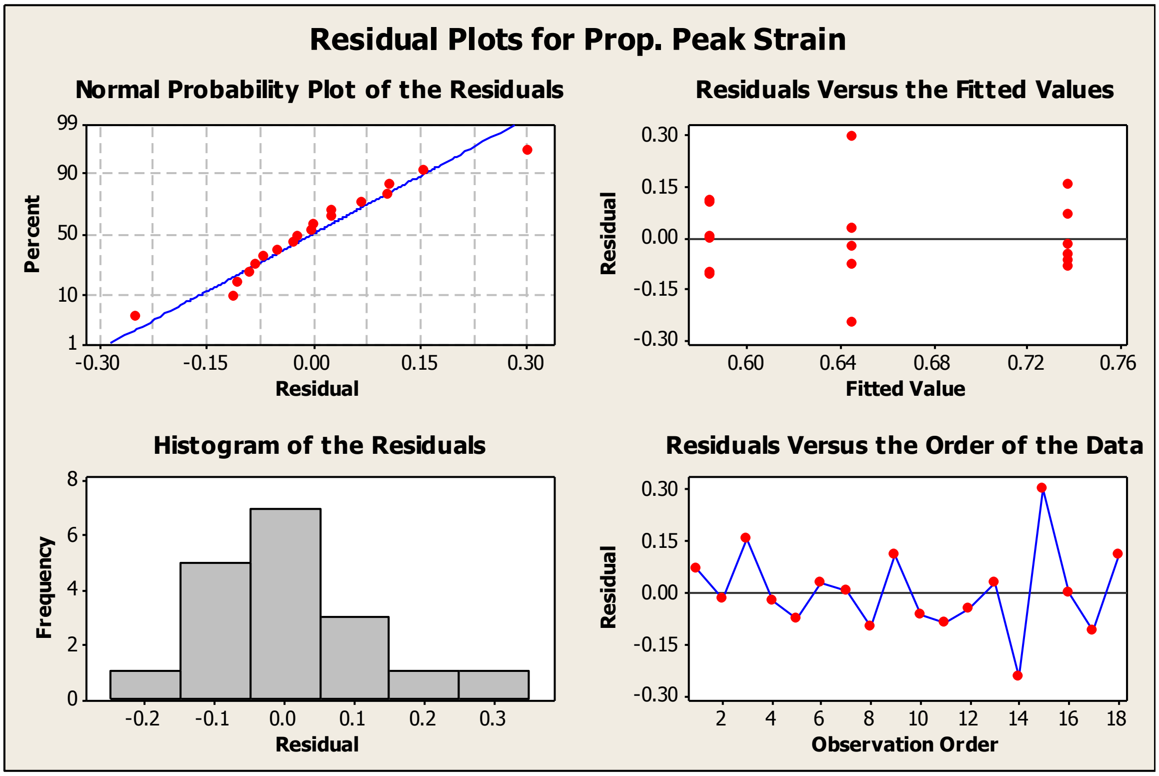

Figure 84: Residual plots for proportional peak strain, material 6

One-way ANOVA: Prop. Peak Strain versus Time for Material 7

```
Source  DF      SS      MS     F      P
Time     2  0.1382  0.0691  4.09  0.038
Error   15  0.2532  0.0169
Total   17  0.3915

S = 0.1299   R-Sq = 35.31%   R-Sq(adj) = 26.68%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level  N    Mean   StDev  ---+---------+---------+---------+------
2      6  0.8778  0.1773                   (---------*---------)
4      6  0.7078  0.0800     (---------*---------)
8      6  0.6792  0.1131  (----------*---------)
                          ---+---------+---------+---------+------
                           0.60      0.72      0.84      0.96

Pooled StDev = 0.1299


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower   Center    Upper  -----+---------+---------+---------+----
4      -0.3646  -0.1700   0.0247    (-----------*------------)
8      -0.3932  -0.1985  -0.0038  (------------*-----------)
                                  -----+---------+---------+---------+----
                                    -0.32     -0.16      0.00      0.16


Time = 4 subtracted from:

Time     Lower   Center   Upper  -----+---------+---------+---------+----
8      -0.2232  -0.0286  0.1661             (-----------*-----------)
                                 -----+---------+---------+---------+----
                                   -0.32     -0.16      0.00      0.16
```

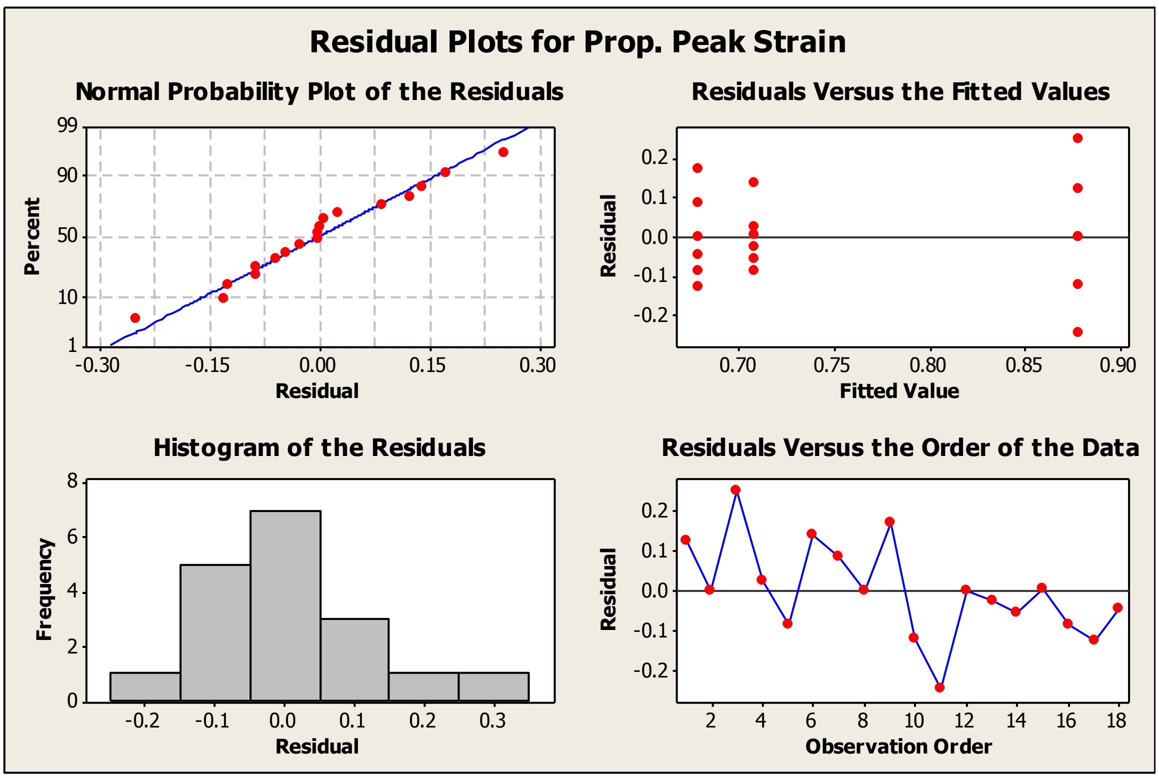

Figure 85: Residual plots for proportional peak strain, material 7

One-way ANOVA: Prop. Peak Strain versus Time for Material 8

```
Source  DF      SS      MS      F      P
Time     2  0.9204  0.4602  43.89  0.000
Error   15  0.1573  0.0105
Total   17  1.0777

S = 0.1024   R-Sq = 85.40%   R-Sq(adj) = 83.46%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
```

```
Level  N    Mean   StDev   -+---------+---------+---------+--------
2      6  0.6017  0.1578                               (---*----)
4      6  0.4310  0.0646                      (----*---)
8      6  0.0600  0.0487   (---*---)
                           -+---------+---------+---------+--------
                          0.00      0.20      0.40      0.60

Pooled StDev = 0.1024


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper     +---------+---------+---------+---------
4     -0.3241  -0.1707  -0.0172                (---*----)
8     -0.6951  -0.5417  -0.3883     (----*---)
                                    +---------+---------+---------+---------
                                 -0.70     -0.35      0.00      0.35


Time = 4 subtracted from:

Time    Lower   Center    Upper     +---------+---------+---------+---------
8     -0.5244  -0.3710  -0.2176          (---*----)
                                    +---------+---------+---------+---------
                                 -0.70     -0.35      0.00      0.35
```

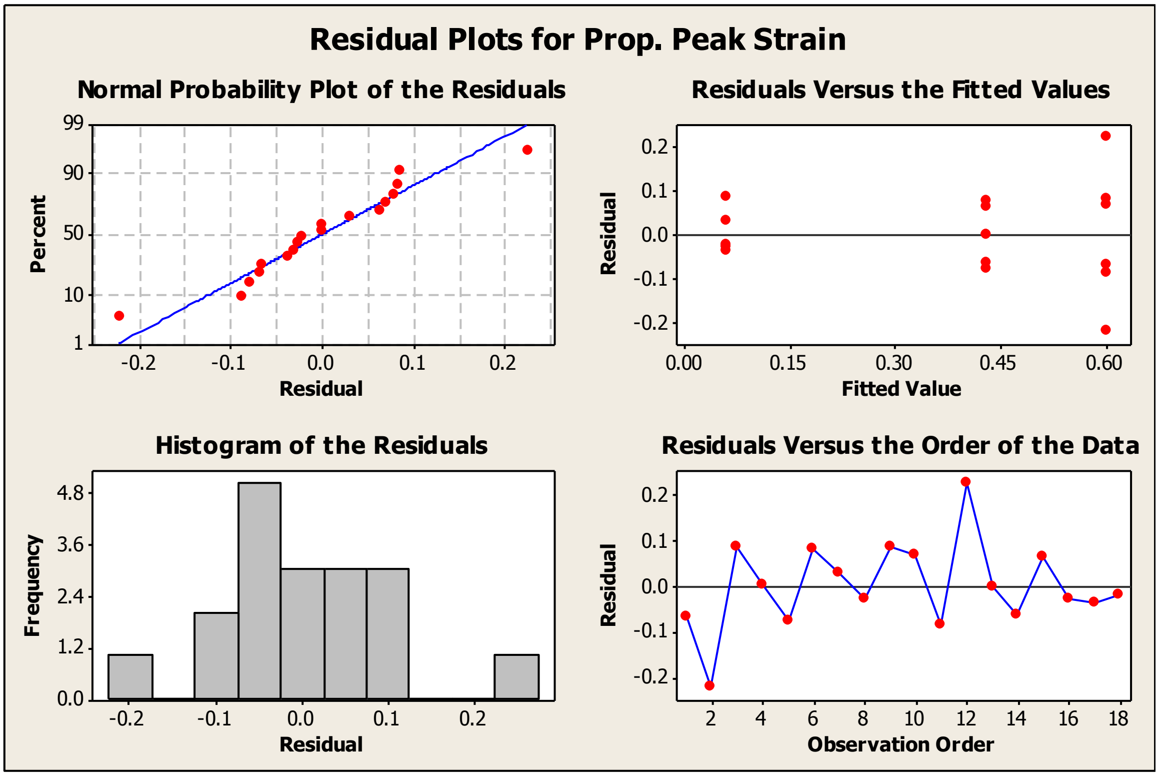

Figure 86: Residual plots for proportional peak strain, material 8

One-way ANOVA: Prop. Peak Strain versus Time for Material 9

```
Source  DF      SS      MS      F      P
Time     2  1.5972  0.7986  55.09  0.000
Error   15  0.2174  0.0145
Total   17  1.8146

S = 0.1204   R-Sq = 88.02%   R-Sq(adj) = 86.42%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -+---------+---------+---------+--------
2      6  0.7964  0.1435                              (---*---)
4      6  0.4021  0.1195               (---*---)
8      6  0.0676  0.0928  (---*---)
                          -+---------+---------+---------+--------
                          0.00      0.25      0.50      0.75

Pooled StDev = 0.1204


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower   Center    Upper   ---+---------+---------+---------+------
4      -0.5747  -0.3943  -0.2139             (---*----)
8      -0.9092  -0.7288  -0.5484   (----*---)
                                   ---+---------+---------+---------+------
                                   -0.80     -0.40     -0.00      0.40


Time = 4 subtracted from:

Time     Lower   Center    Upper   ---+---------+---------+---------+------
8      -0.5150  -0.3346  -0.1542              (----*---)
                                   ---+---------+---------+---------+------
                                   -0.80     -0.40     -0.00      0.40
```

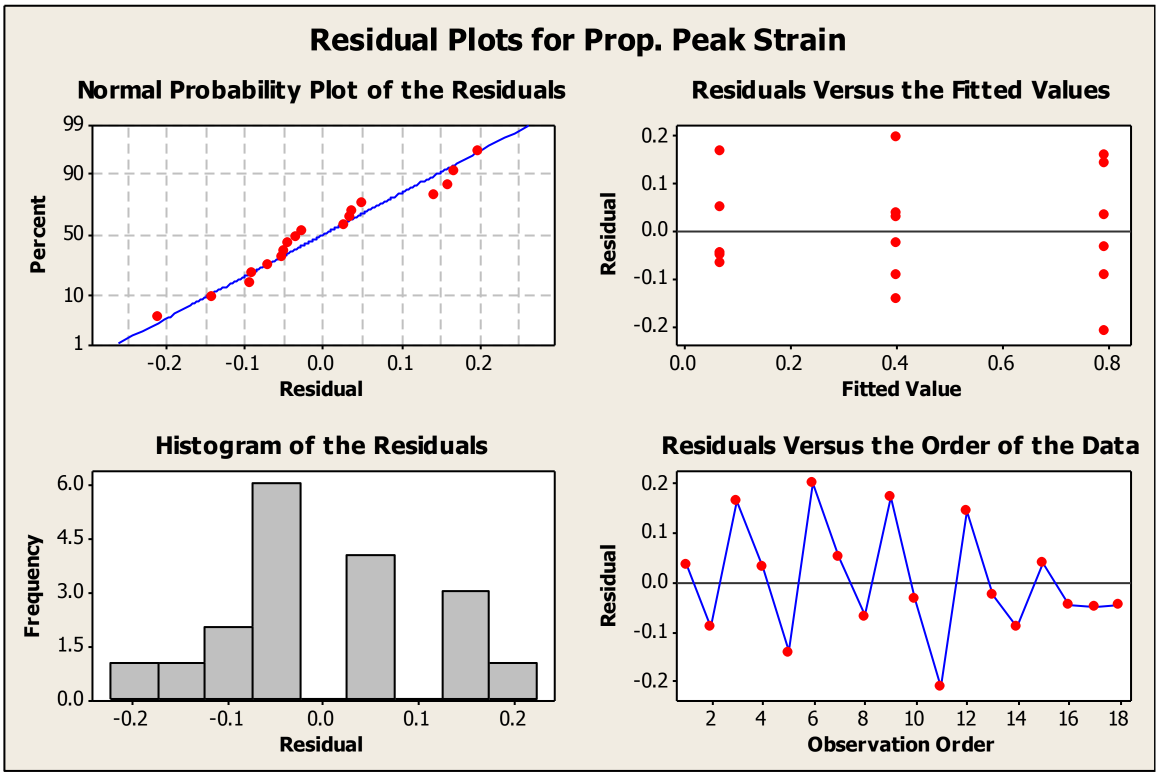

Figure 87: Residual plots for proportional peak strain, material 9

One-way ANOVA: Prop. Peak Strain versus Time for Material 10

```
Source  DF      SS      MS      F      P
Time     2  1.3748  0.6874  54.83  0.000
Error   15  0.1881  0.0125
Total   17  1.5629

S = 0.1120   R-Sq = 87.97%   R-Sq(adj) = 86.36%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
```

```
Level  N    Mean   StDev  --+---------+---------+---------+-------
2      6  0.7238  0.1179                            (---*---)
4      6  0.4877  0.1498                   (---*--)
8      6  0.0563  0.0355  (---*---)
                          --+---------+---------+---------+-------
                          0.00      0.25      0.50      0.75

Pooled StDev = 0.1120


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper    -+---------+---------+---------+--------
4     -0.4039  -0.2361  -0.0684              (---*---)
8     -0.8353  -0.6675  -0.4997    (---*----)
                                   -+---------+---------+---------+--------
                                 -0.80     -0.40     -0.00      0.40


Time = 4 subtracted from:

Time    Lower   Center    Upper    -+---------+---------+---------+--------
8     -0.5991  -0.4314  -0.2636          (---*---)
                                   -+---------+---------+---------+--------
                                 -0.80     -0.40     -0.00      0.40
```

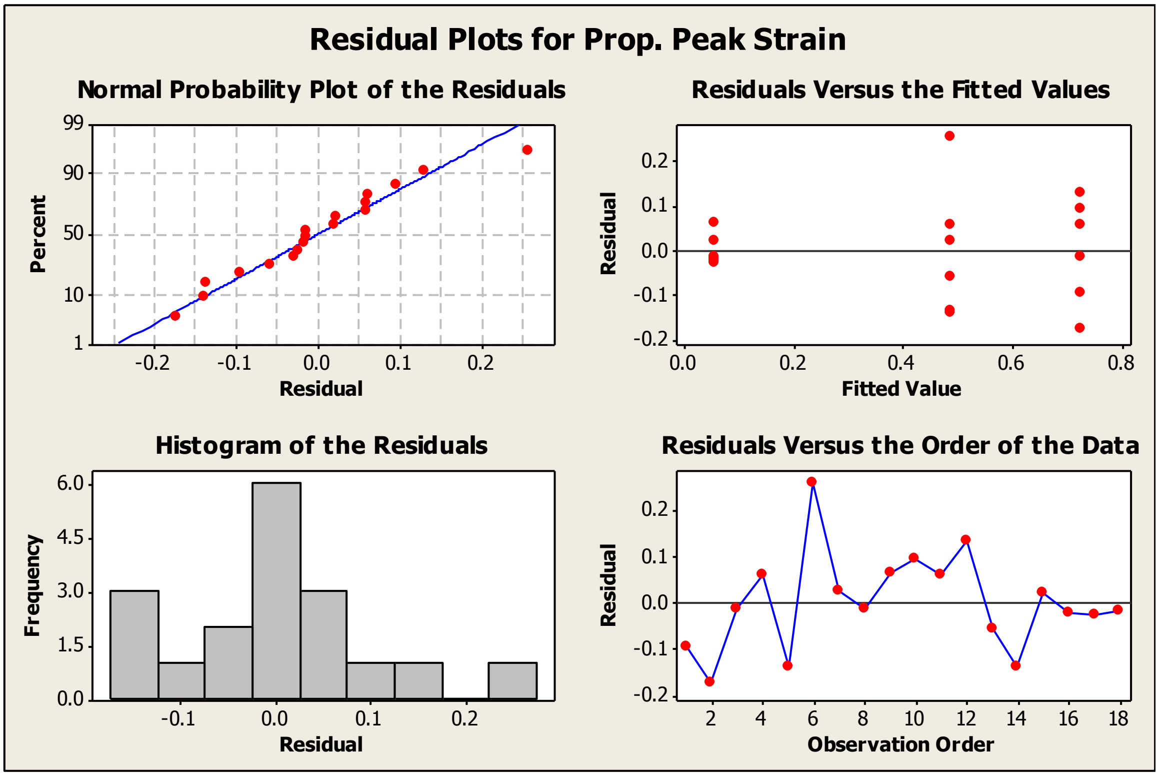

Figure 88: Residual plots for proportional peak strain, material 10

One-way ANOVA: Prop. Peak Strain versus Time for Material 11

```
Source  DF       SS       MS      F      P
Time     2  0.65675  0.32837  56.94  0.000
Error   15  0.08650  0.00577
Total   17  0.74325

S = 0.07594   R-Sq = 88.36%   R-Sq(adj) = 86.81%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  --+---------+---------+---------+-------
2      6  0.50537  0.12037                                (----*---)
4      6  0.29318  0.05195                  (----*---)
8      6  0.03814  0.01064  (----*---)
                            --+---------+---------+---------+-------
                            0.00      0.15      0.30      0.45

Pooled StDev = 0.07594


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time      Lower    Center     Upper  ---+---------+---------+---------+------
4      -0.32597  -0.21219  -0.09841            (----*---)
8      -0.58101  -0.46723  -0.35345  (---*----)
                                     ---+---------+---------+---------+------
                                     -0.50     -0.25      0.00      0.25


Time = 4 subtracted from:

Time      Lower    Center     Upper  ---+---------+---------+---------+------
8      -0.36882  -0.25504  -0.14126          (----*---)
                                     ---+---------+---------+---------+------
                                     -0.50     -0.25      0.00      0.25
```

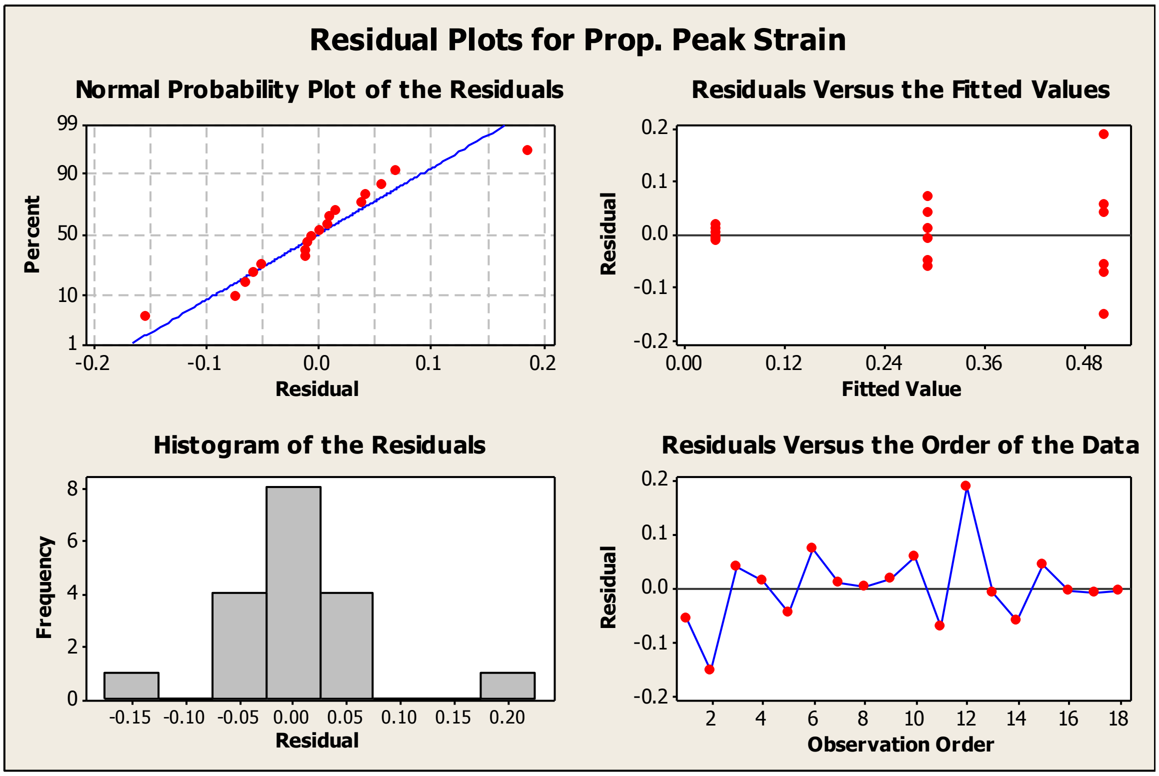

Figure 89: Residual plots for proportional peak strain, material 11

One-way ANOVA: Prop. Peak Strain versus Time for Material 12

```
Source  DF      SS      MS      F      P
Time     2  1.0980  0.5490  48.91  0.000
Error   15  0.1684  0.0112
Total   17  1.2664

S = 0.1059   R-Sq = 86.71%   R-Sq(adj) = 84.93%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   ---+---------+---------+---------+------
```

```
2       6  0.6255  0.1357                                   (---*----)
4       6  0.2682  0.1222                  (---*----)
8       6  0.0240  0.0186  (---*----)
                           ---+---------+---------+---------+------
                            0.00      0.20      0.40      0.60

Pooled StDev = 0.1059


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower   Center    Upper  -----+---------+---------+---------+----
4      -0.5160  -0.3573  -0.1985          (----*----)
8      -0.7602  -0.6015  -0.4427  (----*----)
                                  -----+---------+---------+---------+----
                                     -0.60     -0.30      0.00      0.30


Time = 4 subtracted from:

Time     Lower   Center    Upper  -----+---------+---------+---------+----
8      -0.4029  -0.2442  -0.0855              (----*----)
                                  -----+---------+---------+---------+----
                                     -0.60     -0.30      0.00      0.30
```

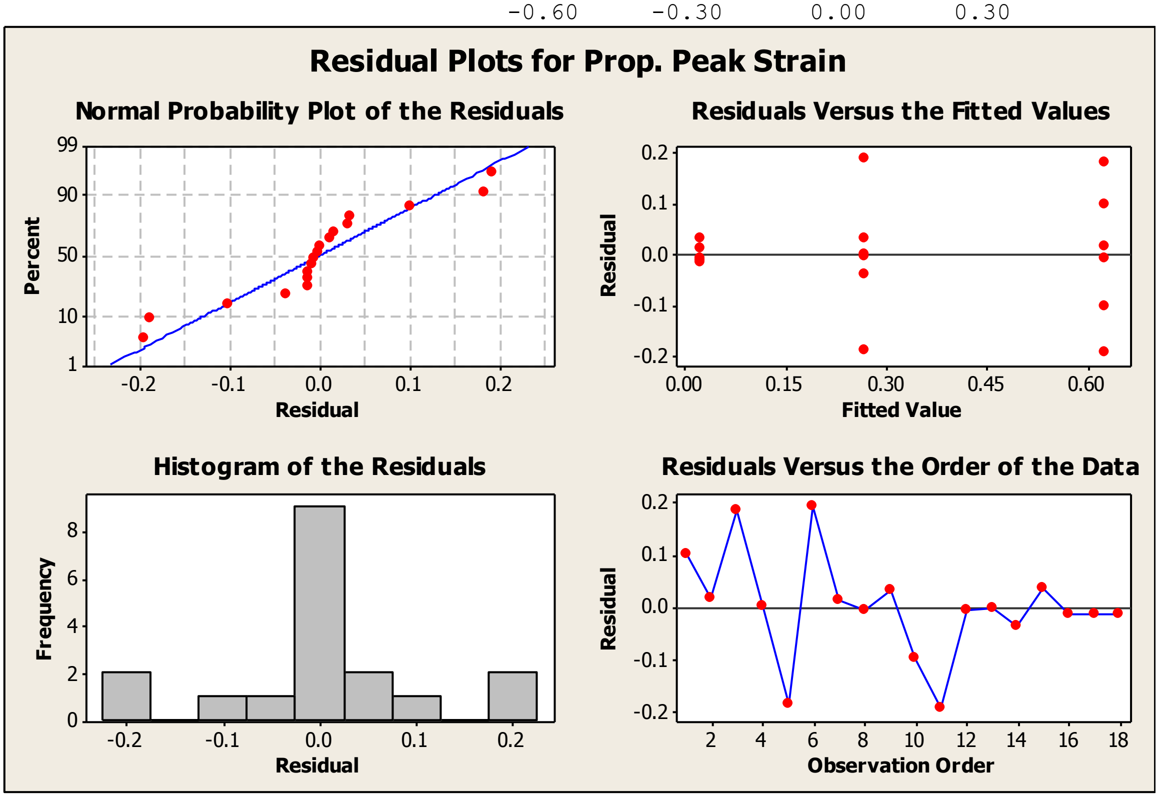

Figure 90: Residual plots for proportional peak strain, material 12

One-way ANOVA: Prop. Peak Strain versus Time for Material 13

```
Source  DF       SS       MS      F      P
Time     2  0.43975  0.21988  38.03  0.000
Error   15  0.08673  0.00578
Total   17  0.52648

S = 0.07604   R-Sq = 83.53%   R-Sq(adj) = 81.33%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  ---+---------+---------+---------+------
2      6  0.38839  0.06487                         (----*---)
4      6  0.09974  0.11438       (----*---)
8      6  0.02623  0.00740  (----*---)
                            ---+---------+---------+---------+------
                             0.00      0.15      0.30      0.45

Pooled StDev = 0.07604


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower    Center     Upper  ----+---------+---------+---------+-----
4     -0.40258  -0.28865  -0.17472      (-----*----)
8     -0.47608  -0.36215  -0.24823  (-----*-----)
                                    ----+---------+---------+---------+-----
                                     -0.40     -0.20     -0.00      0.20


Time = 4 subtracted from:

Time     Lower    Center    Upper  ----+---------+---------+---------+-----
8     -0.18743  -0.07350  0.04042                (----*-----)
                                   ----+---------+---------+---------+-----
                                    -0.40     -0.20     -0.00      0.20
```

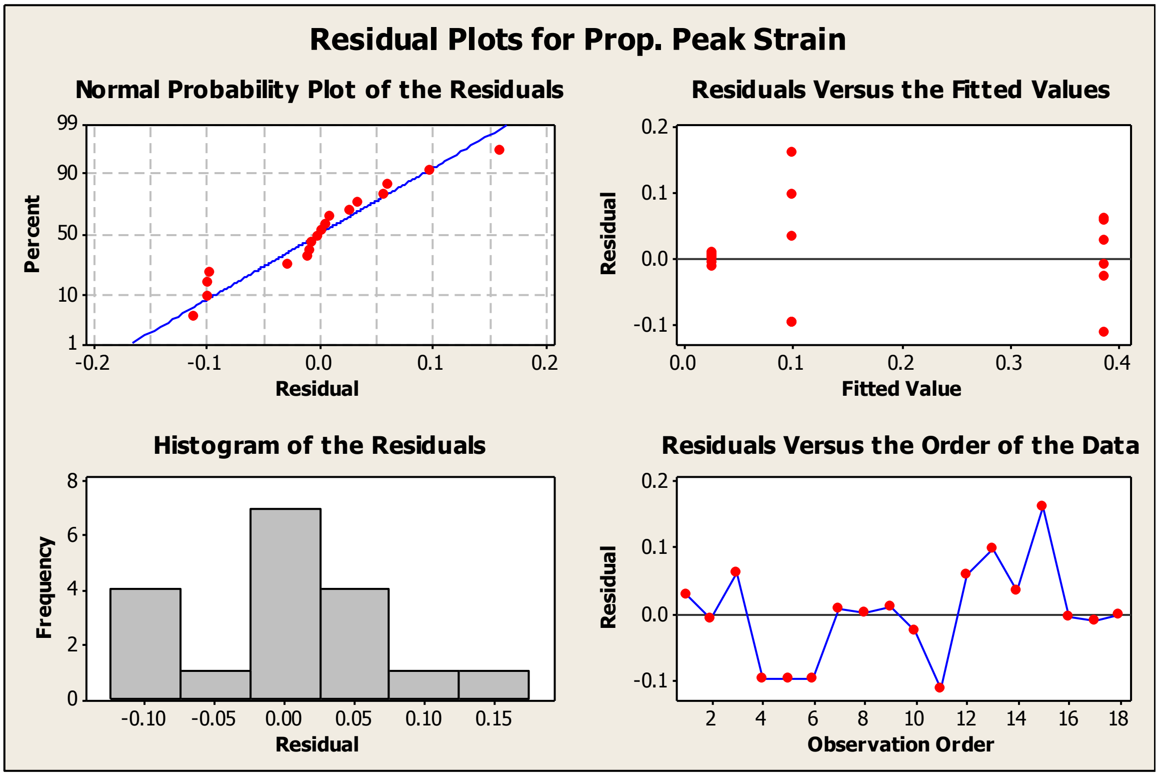

Figure 91: Residual plots for proportional peak strain, material 13

One-way ANOVA: Prop. Peak Strain versus Time for Material 14

```
Source  DF       SS       MS      F      P
Time     2  1.04120  0.52060  54.14  0.000
Error   15  0.14423  0.00962
Total   17  1.18543

S = 0.09806   R-Sq = 87.83%   R-Sq(adj) = 86.21%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N    Mean   StDev   ---------+---------+---------+---------+
2      6  1.0811  0.1072                              (---*---)
4      6  0.8863  0.1217                    (---*----)
8      6  0.5022  0.0506   (---*---)
                           ---------+---------+---------+---------+
                                  0.60      0.80      1.00      1.20

Pooled StDev = 0.0981


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time      Lower    Center     Upper    -+---------+---------+---------+--------
4      -0.34171  -0.19479  -0.04787              (---*----)
8      -0.72581  -0.57890  -0.43198    (---*----)
                                       -+---------+---------+---------+--------
                                     -0.70     -0.35      0.00      0.35


Time = 4 subtracted from:

Time      Lower    Center     Upper    -+---------+---------+---------+--------
8      -0.53103  -0.38411  -0.23719         (---*---)
                                       -+---------+---------+---------+--------
                                     -0.70     -0.35      0.00      0.35
```

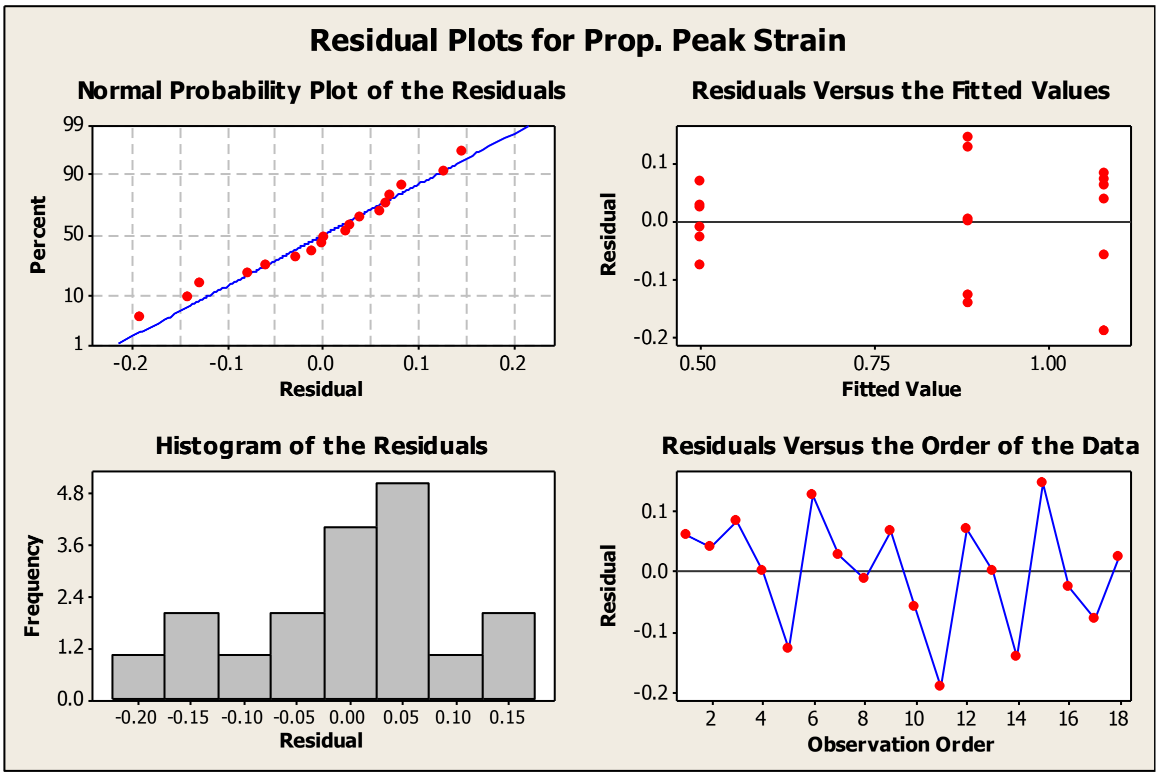

Figure 92: Residual plots for proportional peak strain, material 14

One-way ANOVA: Prop. Peak Strain versus Time for Material 15

```
Source  DF       SS       MS      F      P
Time     2  0.36954  0.18477  41.21  0.000
Error   15  0.06725  0.00448
Total   17  0.43679

S = 0.06696   R-Sq = 84.60%   R-Sq(adj) = 82.55%
```

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ---------+---------+---------+---------+
2      6  1.0234  0.0905                             (----*----)
4      6  0.8798  0.0494                 (----*----)
8      6  0.6743  0.0530  (----*----)
                          ---------+---------+---------+---------+
                                0.72      0.84      0.96      1.08

Pooled StDev = 0.0670


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower    Center     Upper   --+---------+---------+---------+-------
4     -0.24395  -0.14363  -0.04331             (----*----)
8     -0.44947  -0.34915  -0.24882   (----*----)
                                     --+---------+---------+---------+-------
                                     -0.40     -0.20     -0.00      0.20


Time = 4 subtracted from:

Time     Lower    Center     Upper   --+---------+---------+---------+-------
8     -0.30584  -0.20552  -0.10520          (----*----)
                                     --+---------+---------+---------+-------
                                     -0.40     -0.20     -0.00      0.20
```

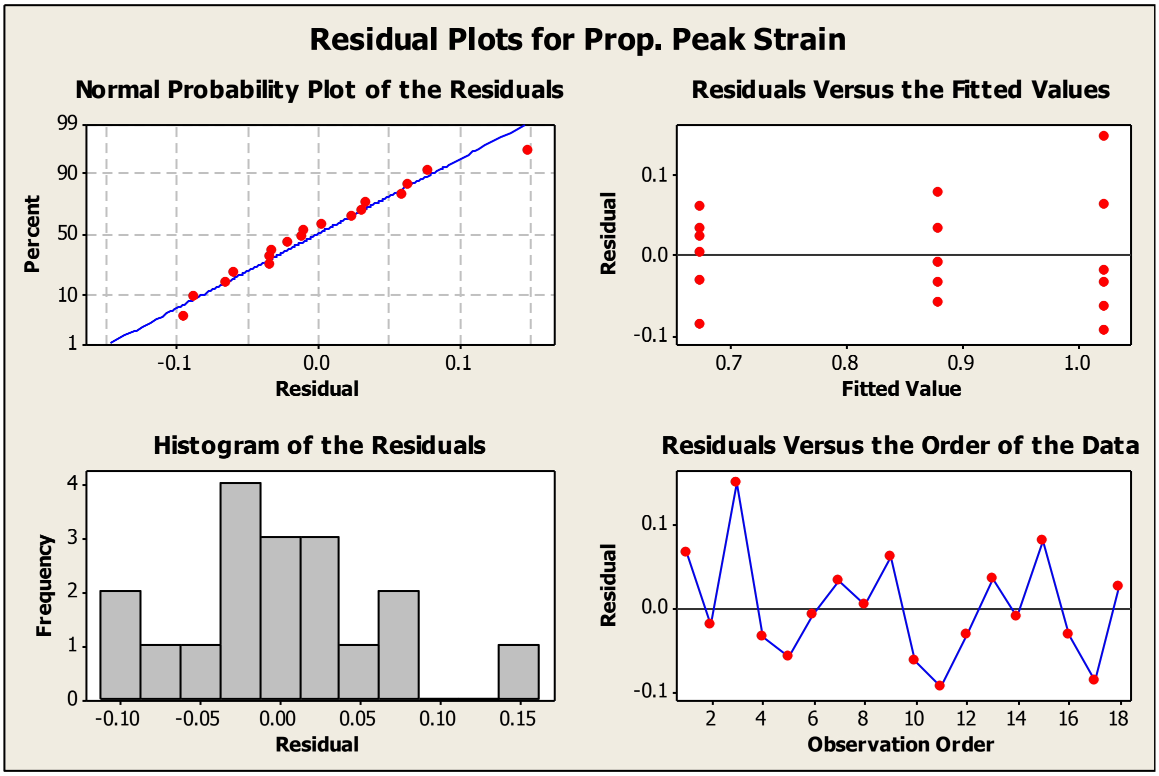

Figure 93: Residual plots for proportional peak strain, material 15

One-way ANOVA: Prop. Peak Strain versus Time for Material 16

```
Source  DF      SS      MS      F      P
Time     2  1.8719  0.9360  16.26  0.000
Error   15  0.8633  0.0576
Total   17  2.7352

S = 0.2399   R-Sq = 68.44%   R-Sq(adj) = 64.23%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ----+---------+---------+---------+-----
2      6  0.8718  0.3342                           (------*------)
4      6  0.6251  0.2450                   (------*------)
8      6  0.0986  0.0304   (------*------)
                          ----+---------+---------+---------+-----
                            0.00      0.30      0.60      0.90

Pooled StDev = 0.2399


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time    Lower   Center    Upper  ---------+---------+---------+---------+
4     -0.6061  -0.2467   0.1127           (-----*-----)
8     -1.1327  -0.7732  -0.4138  (-----*-----)
                                 ---------+---------+---------+---------+
                                      -0.60      0.00      0.60      1.20


Time = 4 subtracted from:

Time    Lower   Center    Upper  ---------+---------+---------+---------+
8     -0.8859  -0.5265  -0.1671      (-----*-----)
                                 ---------+---------+---------+---------+
                                      -0.60      0.00      0.60      1.20
```

Residual Plots for Prop. Peak Strain

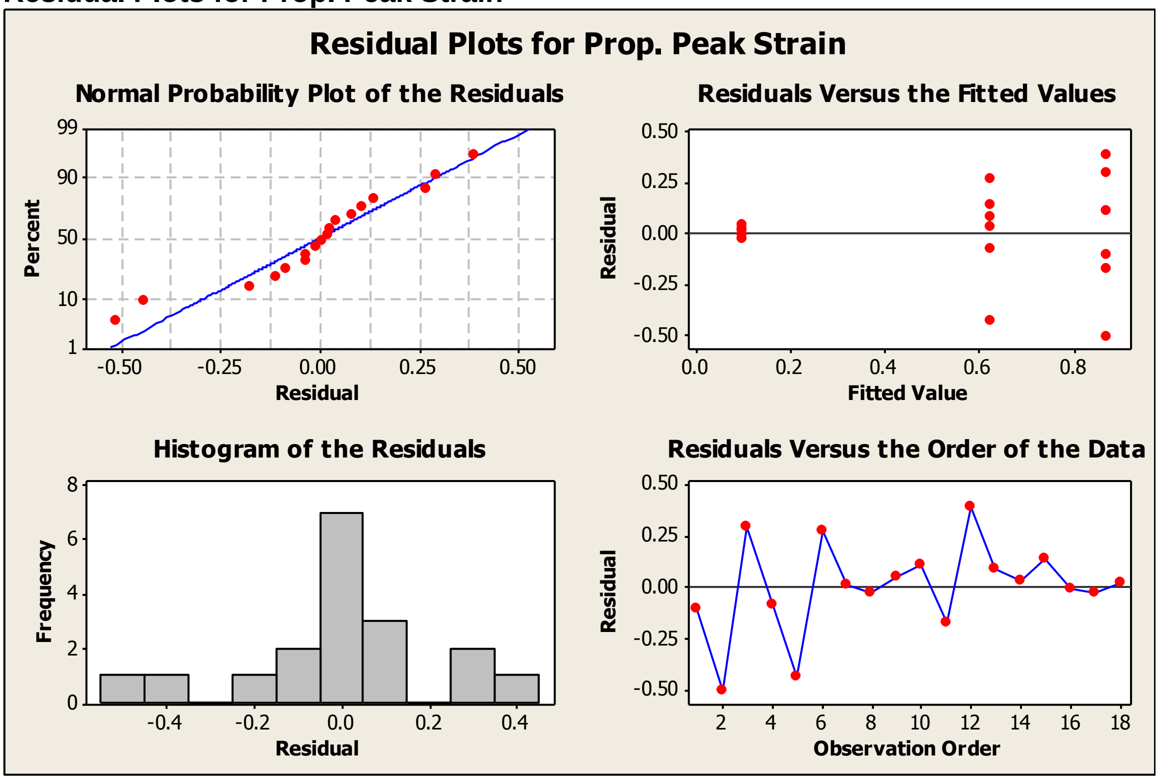

Figure 94: Residual plots for proportional peak strain, material 16

One-way ANOVA: Prop. Peak Strain versus Time for Material 17

```
Source  DF      SS      MS     F      P
Time     2  0.6031  0.3016  5.06  0.021
Error   15  0.8942  0.0596
Total   17  1.4973

S = 0.2442   R-Sq = 40.28%   R-Sq(adj) = 32.32%
```

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev   -+---------+---------+---------+--------
2      6  1.1263  0.3499                     (-------*--------)
4      6  0.8866  0.1207           (-------*--------)
8      6  0.6783  0.2046   (-------*--------)
                           -+---------+---------+---------+--------
                          0.50      0.75      1.00      1.25

Pooled StDev = 0.2442


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper  ---+---------+---------+---------+------
4     -0.6055  -0.2397   0.1261        (---------*----------)
8     -0.8138  -0.4480  -0.0822  (---------*----------)
                                 ---+---------+---------+---------+------
                                 -0.70     -0.35      0.00      0.35


Time = 4 subtracted from:

Time    Lower   Center   Upper  ---+---------+---------+---------+------
8     -0.5741  -0.2083  0.1575         (---------*----------)
                                ---+---------+---------+---------+------
                                -0.70     -0.35      0.00      0.35
```

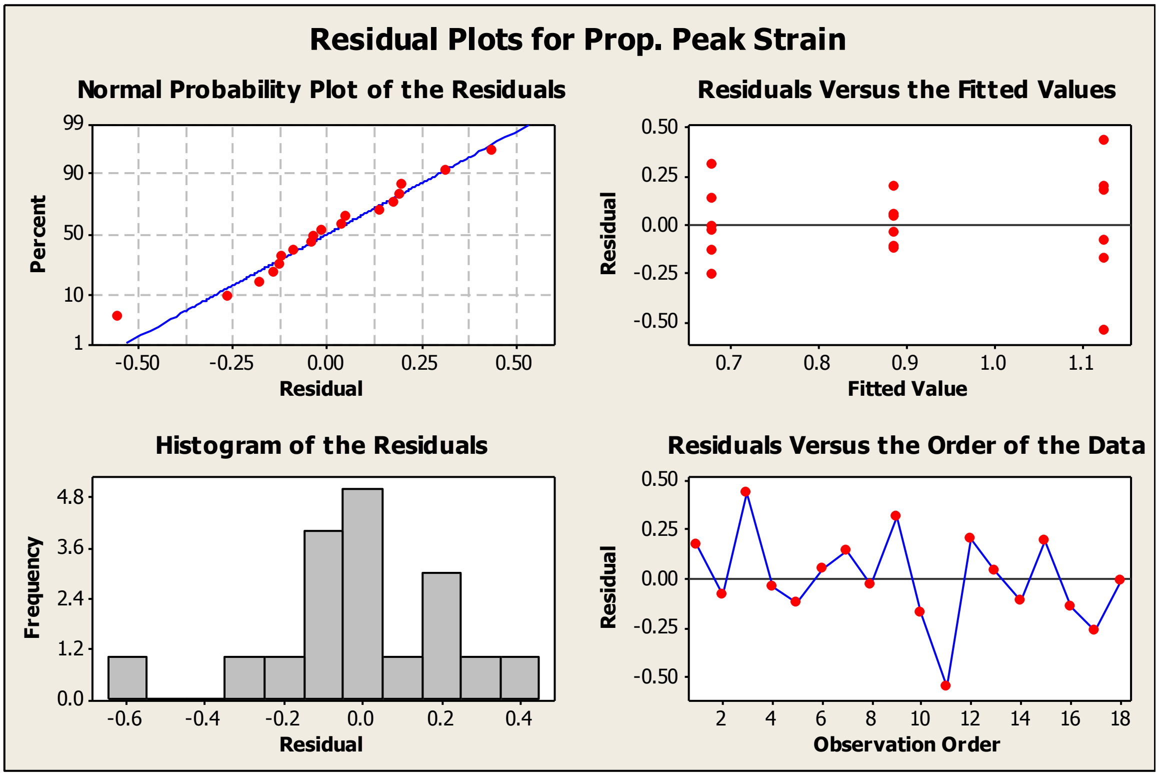

Figure 95: Residual plots for proportional peak strain, material 17

Appendix IV: Peak Stress

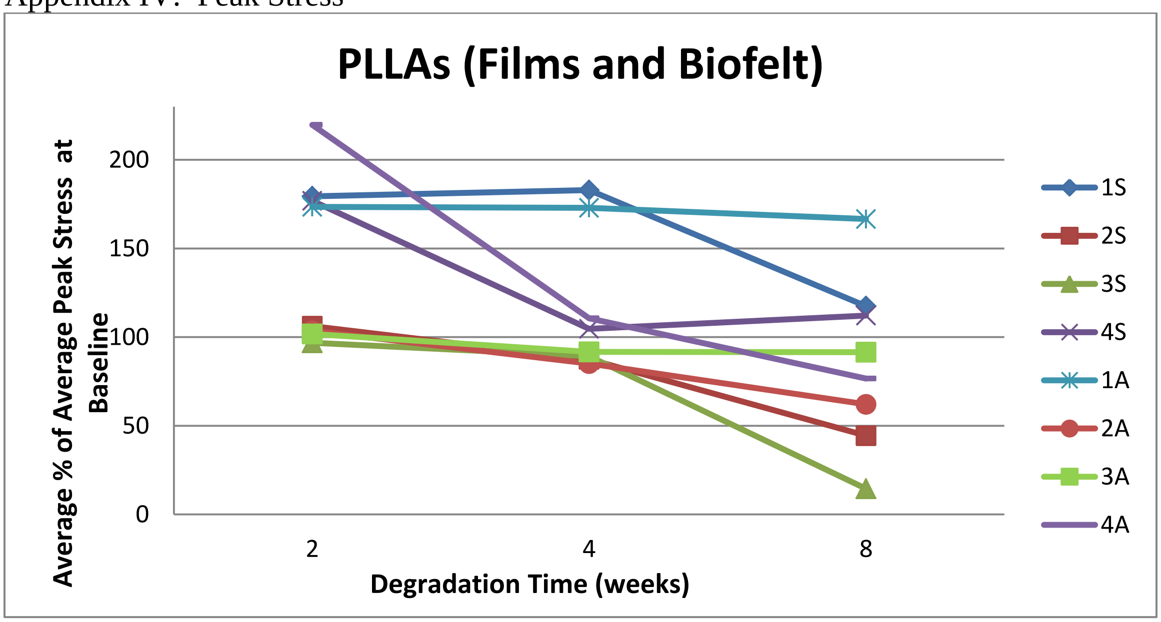

Figure 96: Average percent of baseline average peak stress in PLLA films and biofelt material (materials 1 through 4)

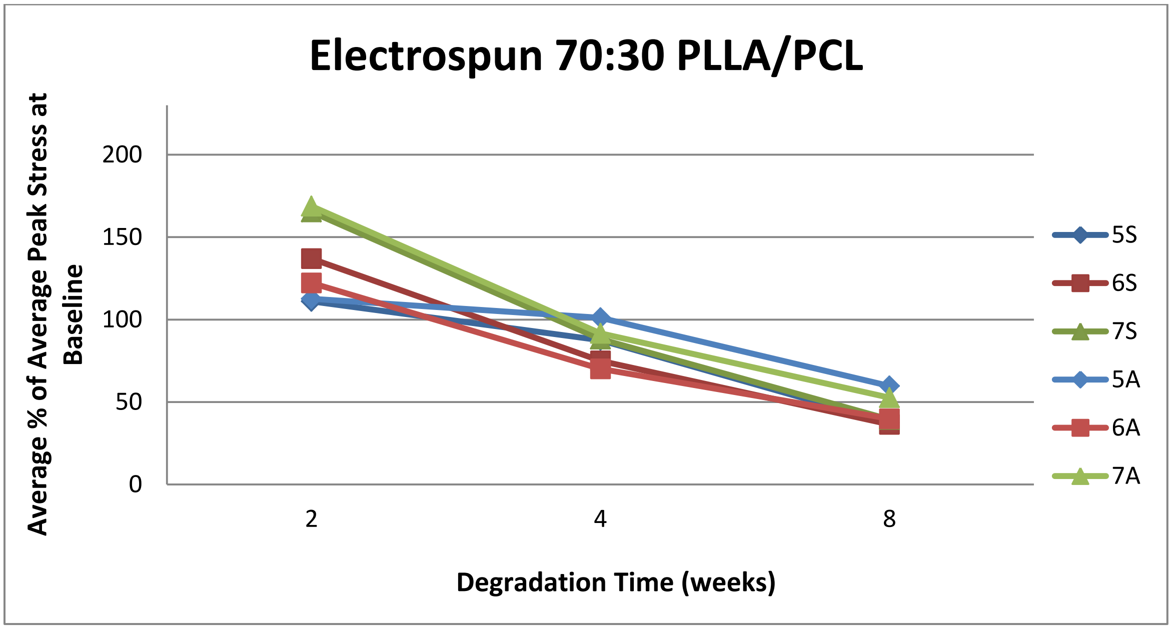

Figure 97: Average percent of baseline peak stress in 70:30 PLLA/PCL electrospun materials

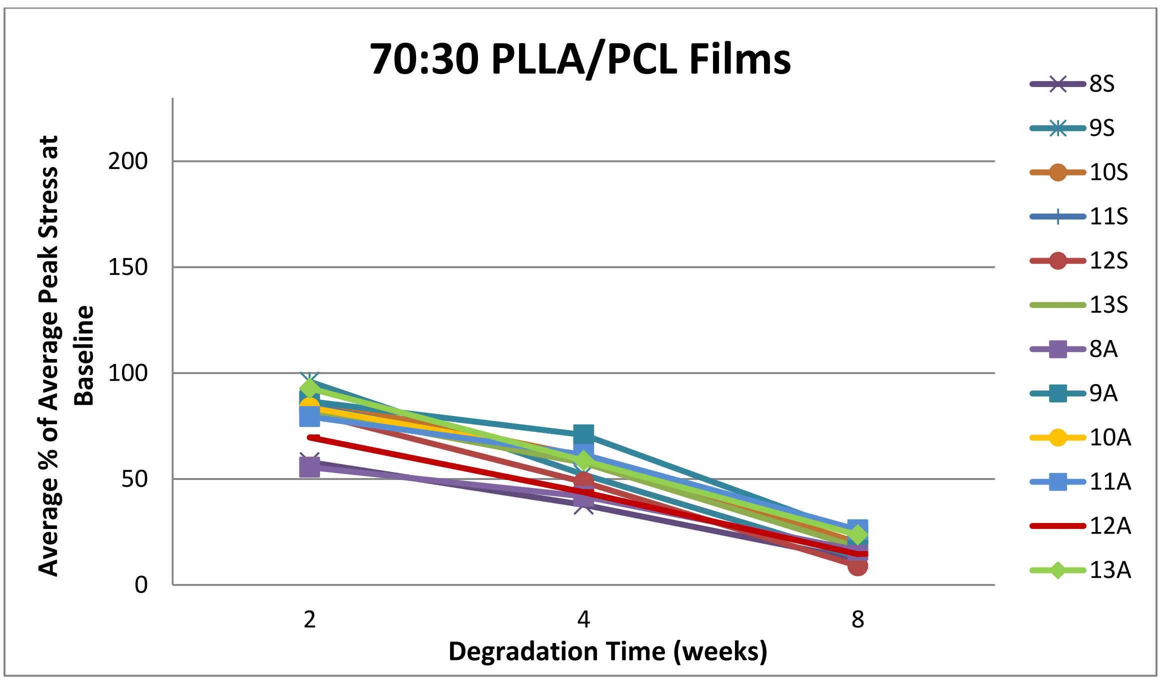

Figure 98: Average percent of average baseline peak stress in 70:30 PLLA/PCL film samples

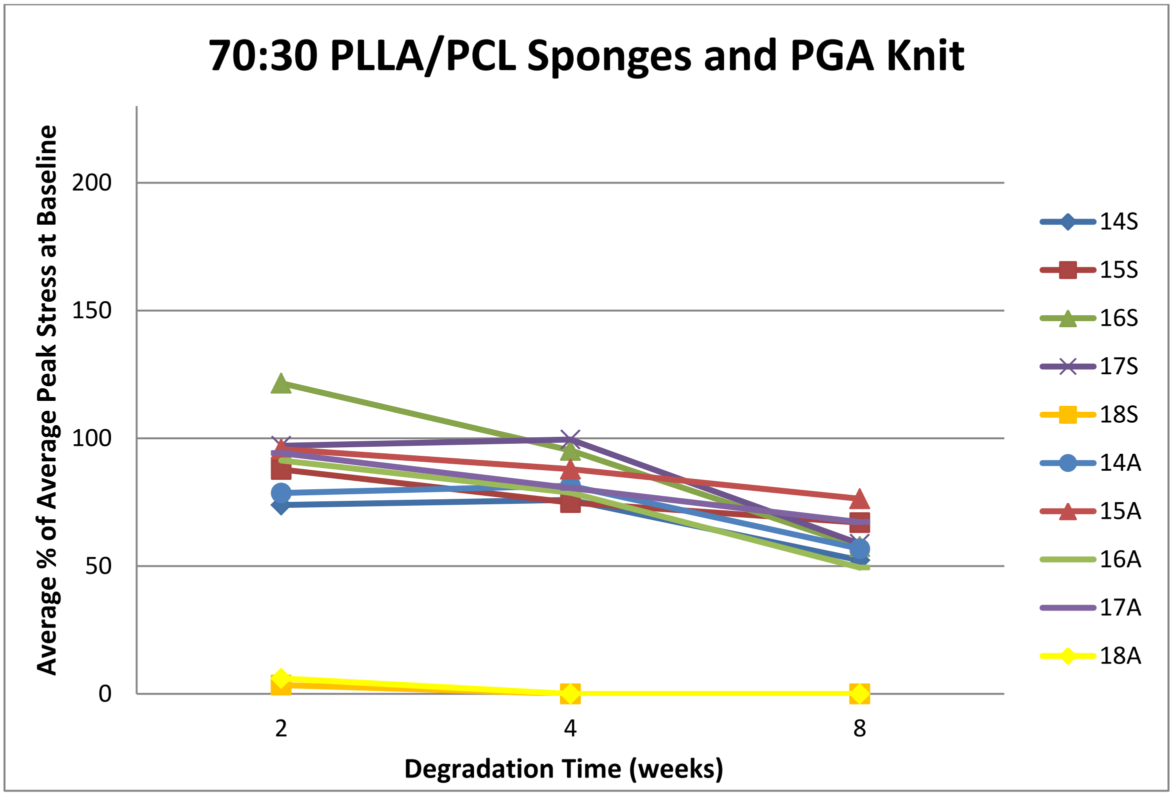

Figure 99: Average percent of baseline average peak stress in 70:30 PLLA/PCL sponges and PGA knit

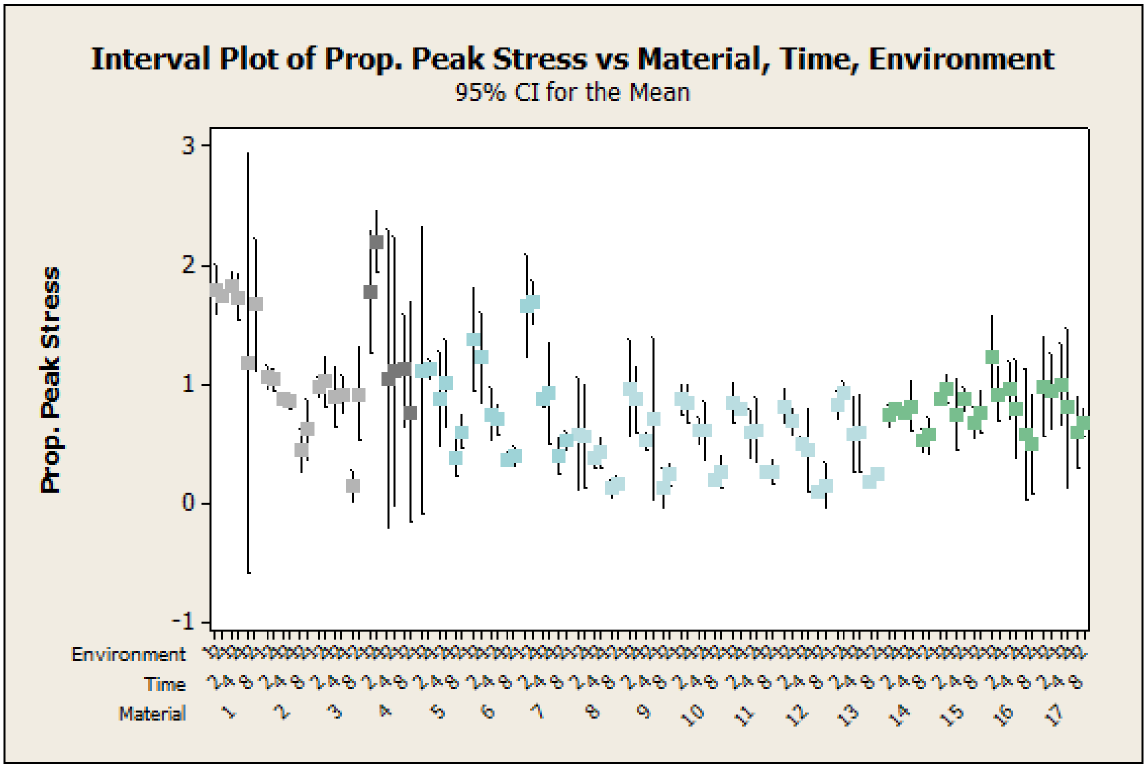

Figure 100: Interval plot of proportional peak stress by material, degradation time and degradation environment

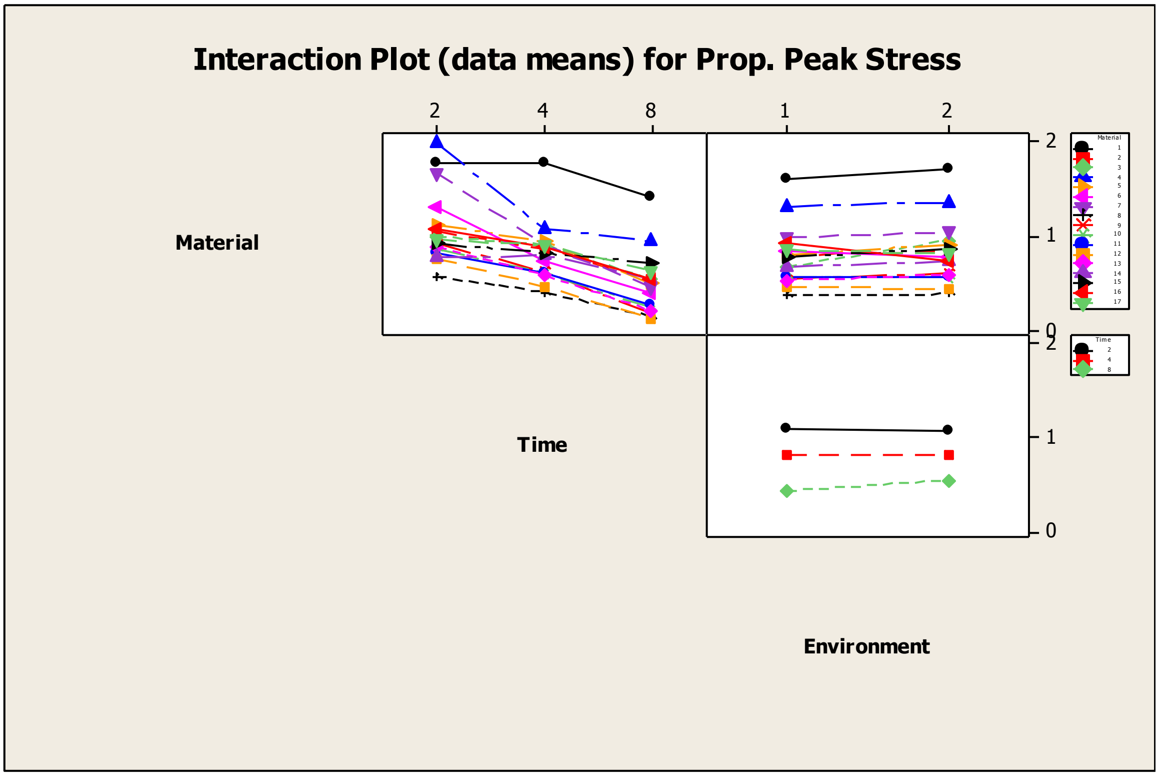

Figure 101: Interaction plot of proportional peak stress, all materials

ANOVA: Proportion of Peak Stress from Baseline versus Material, Degradation Time and Degradation Environment

```
Factor        Type   Levels
Material      fixed      17
Time          fixed       3
Environment   fixed       2

Factor        Values
Material       1,  2,  3,  4,  5,  6,  7,  8,  9, 10, 11, 12, 13, 14, 15, 16, 17
Time          2, 4, 8
Environment   1, 2


Analysis of Variance for Prop. Peak Stress

Source                  DF        SS       MS       F      P
Material                16  29.03511  1.81469   68.56  0.000
Time                     2  17.85454  8.92727  337.28  0.000
Environment              1   0.11165  0.11165    4.22  0.041
Material*Environment    16   0.67936  0.04246    1.60  0.068
Material*Time           32   4.81372  0.15043    5.68  0.000
Time*Environment         2   0.22322  0.11161    4.22  0.016
Error                  236   6.24652  0.02647
Total                  305  58.96412
```

S = 0.162691   R-Sq = 89.41%   R-Sq(adj) = 86.31%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 102 Q[2]
3	Environment		7	(7) + 153 Q[3]
4	Material*Environment		7	(7) + 9 Q[4]
5	Material*Time		7	(7) + 6 Q[5]
6	Time*Environment		7	(7) + 51 Q[6]
7	Error	0.02647		(7)

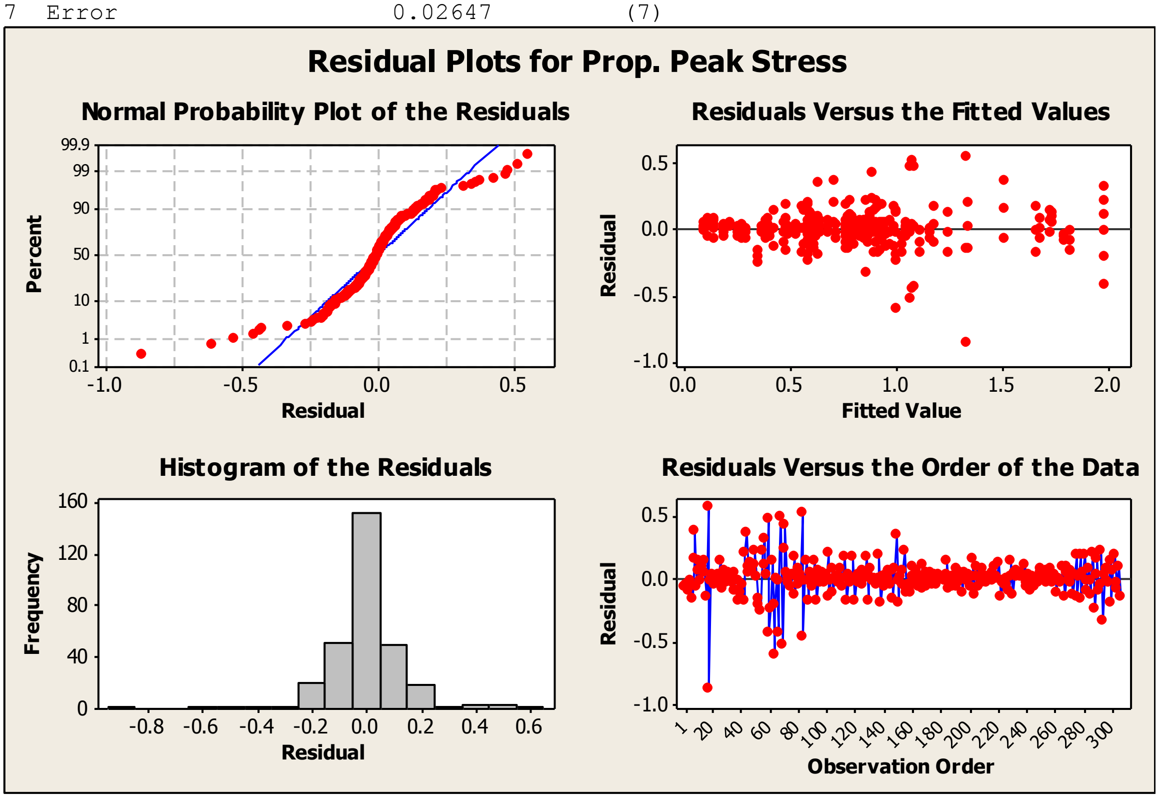

Figure 102: Residual plots of proportional peak stress, all materials

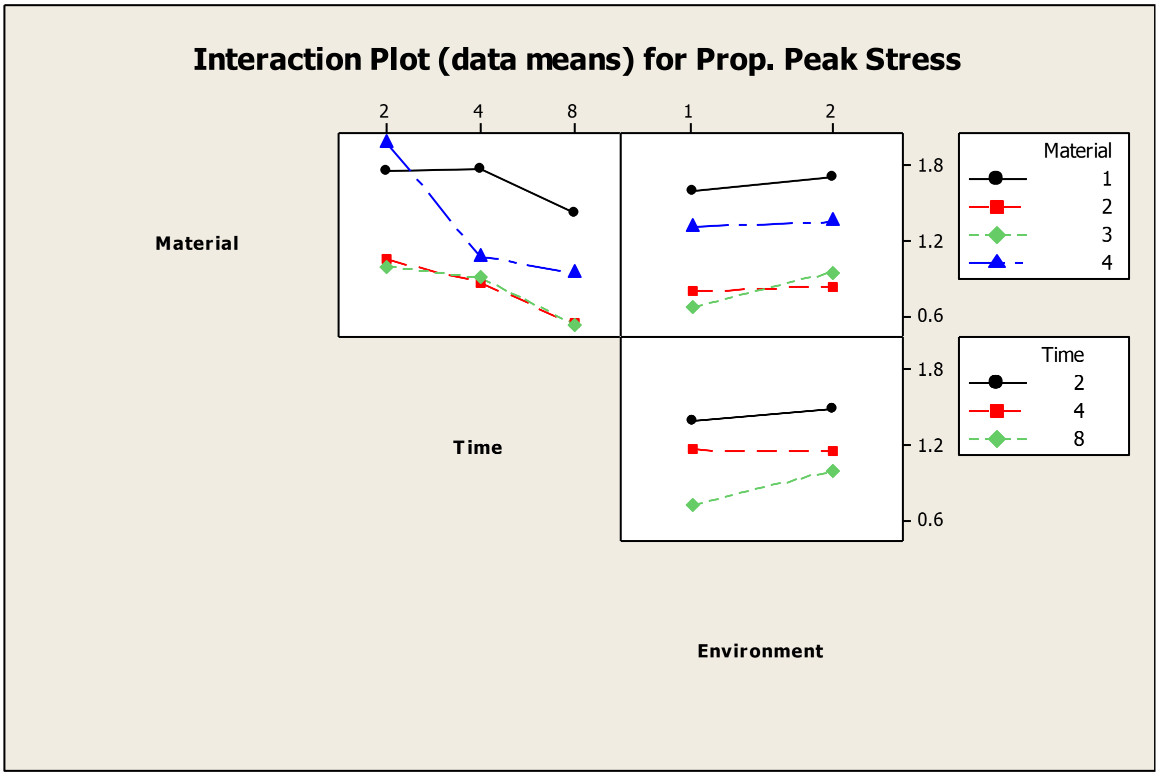

Figure 103: Interaction plot of proportional peak stress, materials 1-4

ANOVA: Prop. Peak Stress versus Material, Time, Environment

Factor	Type	Levels	Values
Material	fixed	4	1, 2, 3, 4
Time	fixed	3	2, 4, 8
Environment	fixed	2	1, 2

Analysis of Variance for Prop. Peak Stress

Source	DF	SS	MS	F	P
Material	3	9.30883	3.10294	44.12	0.000
Time	2	4.18560	2.09280	29.75	0.000
Environment	1	0.25714	0.25714	3.66	0.061
Material*Environment	3	0.17022	0.05674	0.81	0.496
Material*Time	6	1.69213	0.28202	4.01	0.002
Time*Environment	2	0.24088	0.12044	1.71	0.190
Error	54	3.79806	0.07033		
Total	71	19.65286			

S = 0.265206   R-Sq = 80.67%   R-Sq(adj) = 74.59%

Expected Mean
Square for
Each Term
(using

	Source	Variance component	Error term	restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 24 Q[2]
3	Environment		7	(7) + 36 Q[3]
4	Material*Environment		7	(7) + 9 Q[4]
5	Material*Time		7	(7) + 6 Q[5]
6	Time*Environment		7	(7) + 12 Q[6]
7	Error	0.07033		(7)

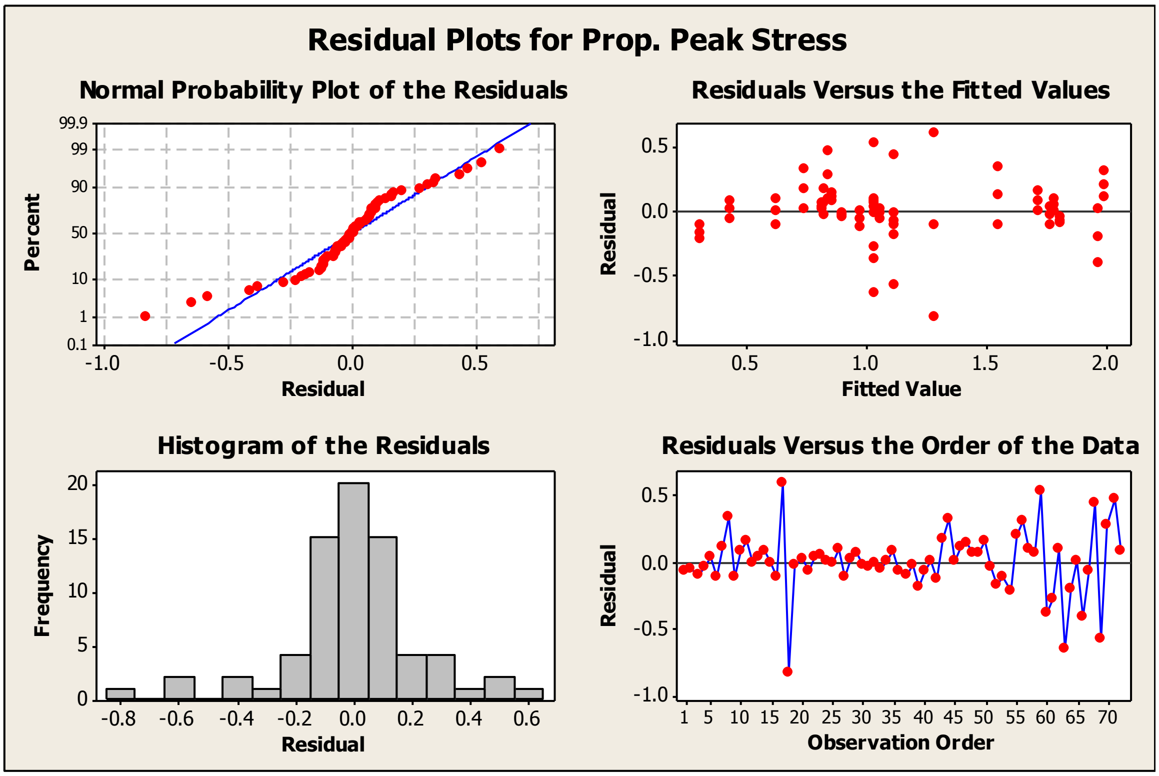

Figure 104: Residual plots of proportional peak stress, materials 1-4

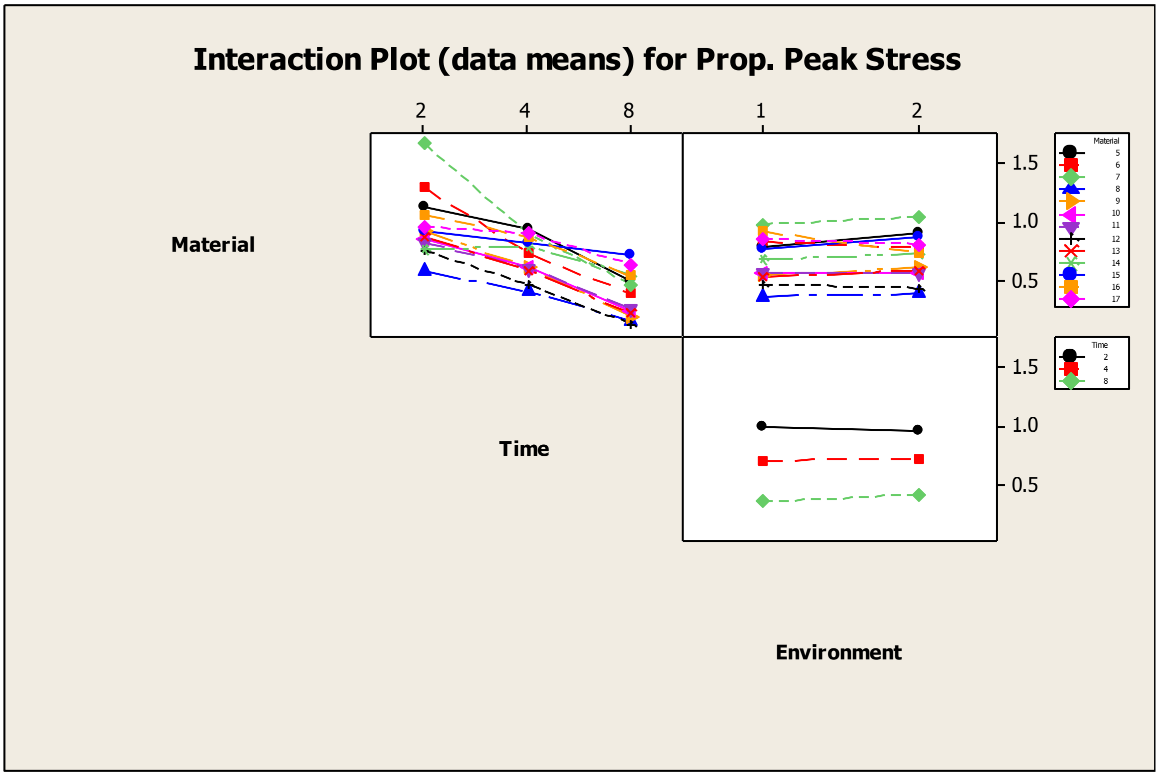

Figure 105: Interaction plot of proportional peak stress, materials 5-17

ANOVA: Proportional Peak Stress from Baseline versus Material, Degradation Time and Degradation Environment (materials 5-17)

```
Factor         Type   Levels  Values
Material       fixed      13   5,  6,  7,  8,  9, 10, 11, 12, 13, 14, 15, 16, 17
Time           fixed       3  2, 4, 8
Environment    fixed       2  1, 2


Analysis of Variance for Prop. Peak Stress

Source                  DF        SS       MS       F      P
Material                12   7.58489  0.63207   48.99  0.000
Time                     2  13.68160  6.84080  530.20  0.000
Environment              1   0.01017  0.01017    0.79  0.376
Material*Environment    12   0.35348  0.02946    2.28  0.010
Material*Time           24   3.10893  0.12954   10.04  0.000
Time*Environment         2   0.10839  0.05420    4.20  0.016
Error                  180   2.32240  0.01290
Total                  233  27.16986


S = 0.113588   R-Sq = 91.45%   R-Sq(adj) = 88.94%


                                           Expected Mean
```

	Source	Variance component	Error term	Square for Each Term (using restricted model)
1	Material		7	(7) + 18 Q[1]
2	Time		7	(7) + 78 Q[2]
3	Environment		7	(7) + 117 Q[3]
4	Material*Environment		7	(7) + 9 Q[4]
5	Material*Time		7	(7) + 6 Q[5]
6	Time*Environment		7	(7) + 39 Q[6]
7	Error	0.01290		(7)

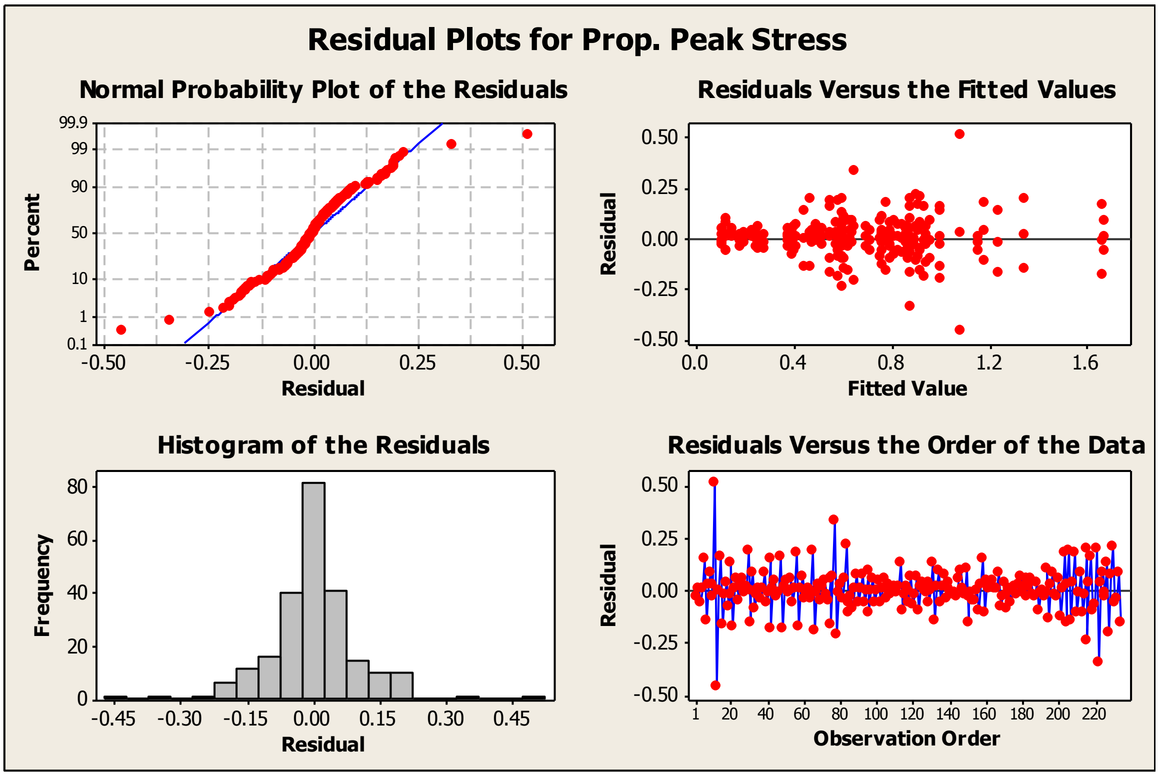

Figure 106: Residual plots for proportional peak stress, materials 5-17

Minitab Project Report

One-way ANOVA: Prop. Peak Stress versus Time for Material 1

Source	DF	SS	MS	F	P
Time	2	0.495	0.248	2.43	0.121
Error	15	1.526	0.102		
Total	17	2.021			

S = 0.3190   R-Sq = 24.50%   R-Sq(adj) = 14.44%

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  ----+---------+---------+---------+-----
2      6  1.7645  0.0635              (-----------*----------)
4      6  1.7796  0.0784               (----------*----------)
8      6  1.4204  0.5432  (----------*----------)
                          ----+---------+---------+---------+-----
                            1.25      1.50      1.75      2.00

Pooled StDev = 0.3190


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center   Upper  -------+---------+---------+---------+--
4     -0.4627   0.0152  0.4931          (--------*---------)
8     -0.8219  -0.3440  0.1338   (--------*---------)
                                -------+---------+---------+---------+--
                                    -0.50      0.00      0.50      1.00


Time = 4 subtracted from:

Time    Lower   Center   Upper  -------+---------+---------+---------+--
8     -0.8371  -0.3592  0.1186  (---------*--------)
                                -------+---------+---------+---------+--
                                    -0.50      0.00      0.50      1.00
```

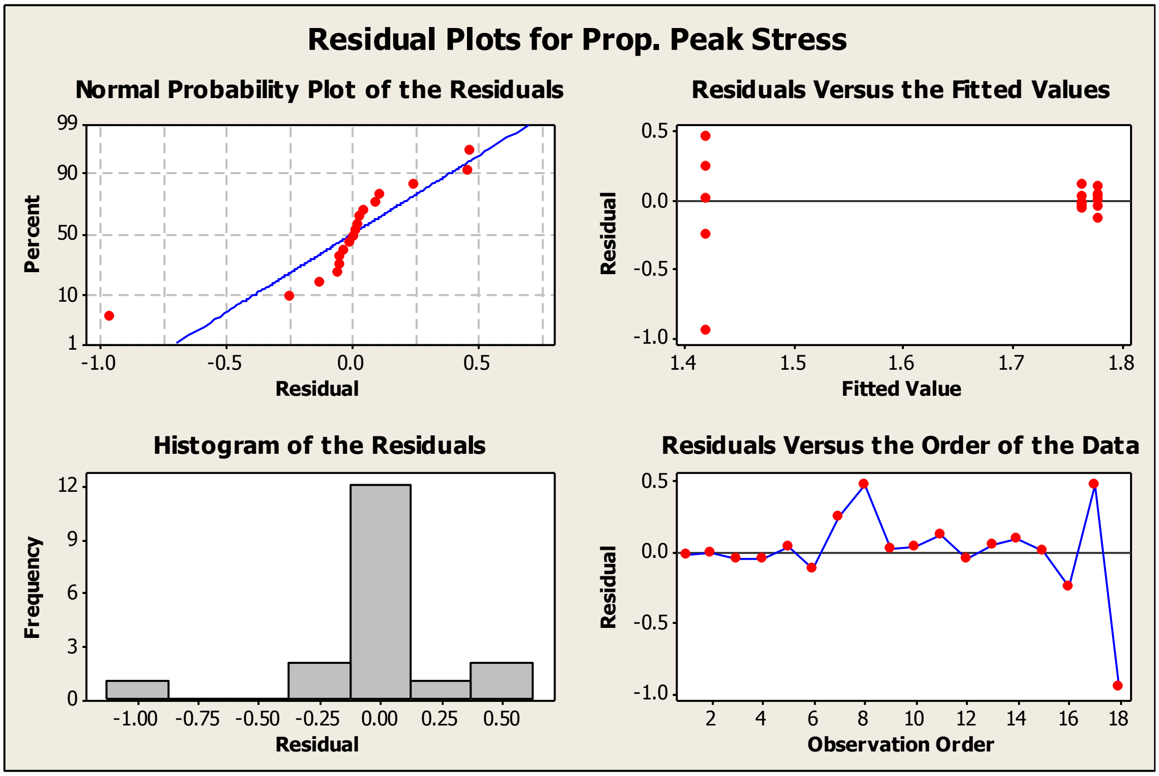

Figure 107: Residual plots for proportional peak stress, material 1

One-way ANOVA: Prop. Peak Stress versus Time for Material 2

```
Source  DF       SS       MS      F      P
Time     2  0.82103  0.41051  68.01  0.000
Error   15  0.09054  0.00604
Total   17  0.91156

S = 0.07769   R-Sq = 90.07%   R-Sq(adj) = 88.74%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -------+---------+---------+---------+--
2      6  1.0491  0.0385                             (--*---)
4      6  0.8632  0.0239                    (--*---)
8      6  0.5327  0.1267  (---*--)
                          -------+---------+---------+---------+--
                               0.60      0.80      1.00      1.20

Pooled StDev = 0.0777


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time       Lower     Center      Upper    -+---------+---------+---------+--------
4      -0.30230  -0.18590  -0.06950               (---*---)
8      -0.63283  -0.51643  -0.40003    (---*---)
                                      -+---------+---------+---------+--------
                                    -0.60     -0.30      0.00      0.30


Time = 4 subtracted from:

Time       Lower     Center      Upper    -+---------+---------+---------+--------
8      -0.44694  -0.33053  -0.21413          (---*---)
                                      -+---------+---------+---------+--------
```

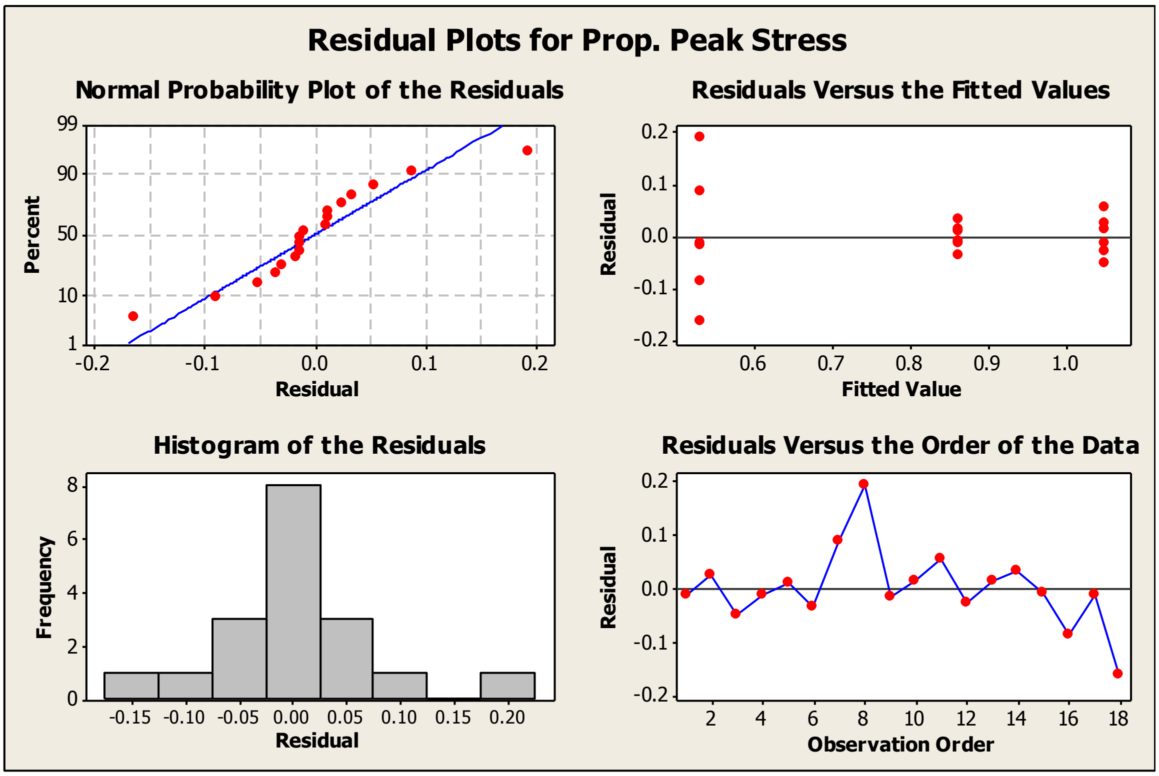

Figure 108: Residual plots for proportional peak stress, material 2

One-way ANOVA: Prop. Peak Stress versus Time for Material 3

```
Source  DF      SS      MS     F      P
Time     2  0.7241  0.3620  5.46  0.017
Error   15  0.9943  0.0663
Total   17  1.7184

S = 0.2575   R-Sq = 42.14%   R-Sq(adj) = 34.42%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --------+---------+---------+---------+-
```

```
2       6  0.9929  0.0620                           (---------*---------)
4       6  0.9046  0.0763                       (---------*---------)
8       6  0.5302  0.4350  (---------*---------)
                           --------+---------+---------+---------+-
                                 0.50      0.75      1.00      1.25

Pooled StDev = 0.2575


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower   Center     Upper  -------+---------+---------+---------+--
4      -0.4740  -0.0883    0.2975          (------*-------)
8      -0.8484  -0.4627   -0.0769  (-------*------)
                                   -------+---------+---------+---------+--
                                       -0.50      0.00      0.50      1.00


Time = 4 subtracted from:

Time     Lower   Center    Upper  -------+---------+---------+---------+--
8      -0.7601  -0.3744   0.0114    (-------*------)
                                  -------+---------+---------+---------+--
                                      -0.50      0.00      0.50      1.00
```

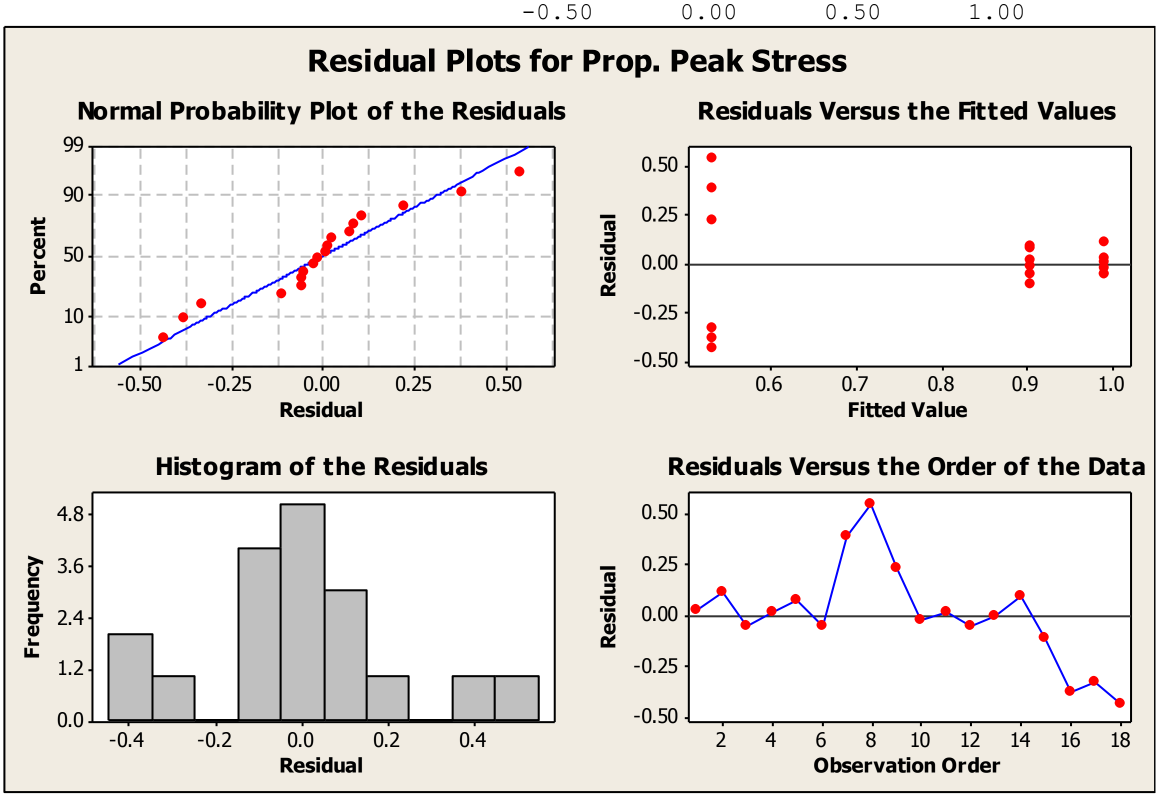

Figure 109: Residual plots for proportional peak stress, material 3

One-way ANOVA: Prop. Peak Stress versus Time for Material 4

```
Source  DF     SS     MS      F      P
Time     2  3.837  1.919  15.51  0.000
Error   15  1.855  0.124
Total   17  5.693

S = 0.3517   R-Sq = 67.41%   R-Sq(adj) = 63.06%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -------+---------+---------+---------+--
2      6  1.9828  0.2773                      (-----*-----)
4      6  1.0766  0.4318    (------*-----)
8      6  0.9436  0.3282  (-----*-----)
                          -------+---------+---------+---------+--
                               1.00      1.50      2.00      2.50

Pooled StDev = 0.3517


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper  ------+---------+---------+---------+---
4     -1.4331  -0.9062  -0.3792    (---------*---------)
8     -1.5661  -1.0391  -0.5122  (---------*--------)
                                 ------+---------+---------+---------+---
                                     -1.20     -0.60      0.00      0.60


Time = 4 subtracted from:

Time    Lower   Center   Upper  ------+---------+---------+---------+---
8     -0.6599  -0.1330  0.3940               (---------*---------)
                                ------+---------+---------+---------+---
                                    -1.20     -0.60      0.00      0.60
```

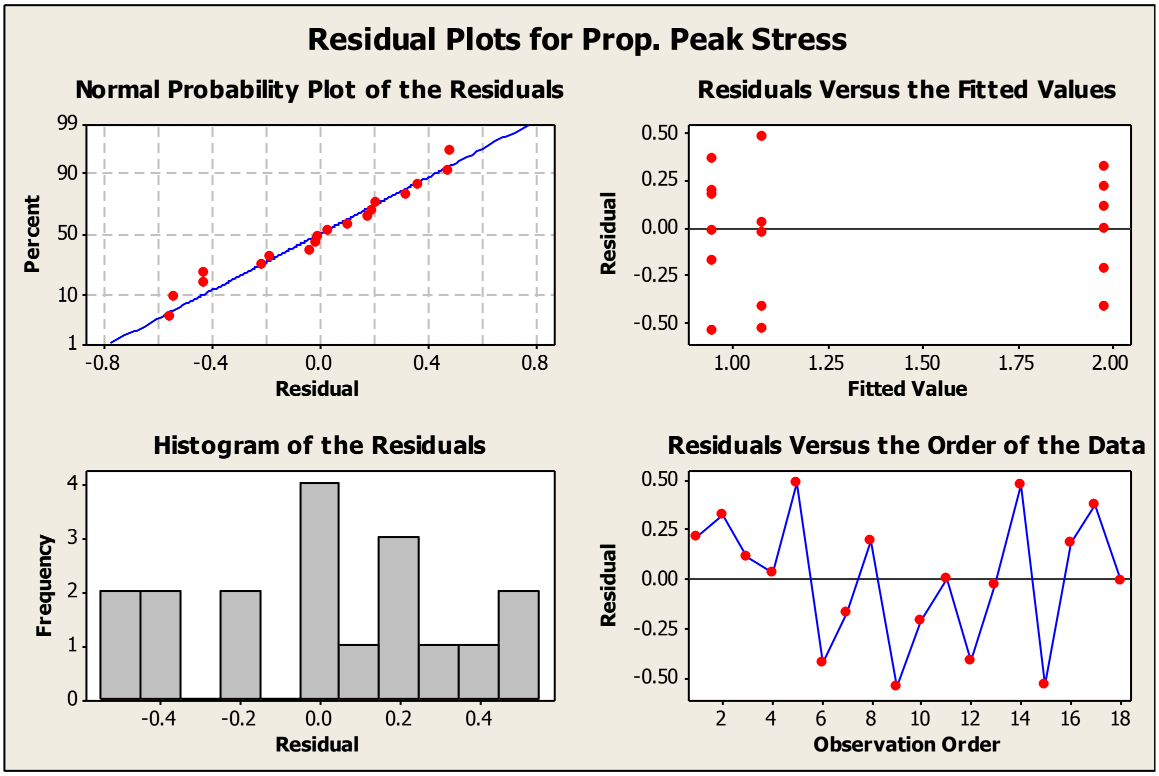

Figure 110: Residual plots for proportional peak stress, material 4

One-way ANOVA: Prop. Peak Stress versus Time for Material 5

```
Source  DF      SS      MS      F      P
Time     2  1.2775  0.6387  13.93  0.000
Error   15  0.6877  0.0458
Total   17  1.9652

S = 0.2141   R-Sq = 65.01%   R-Sq(adj) = 60.34%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev   ---------+---------+---------+---------
2      6  1.1184  0.3084                       (-----*-----)
4      6  0.9424  0.1581                 (-----*------)
8      6  0.4862  0.1320    (-----*-----)
                           ---------+---------+---------+---------
                          0.30      0.60      0.90      1.20

Pooled StDev = 0.2141


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower    Center     Upper  ---------+---------+---------+---------+
4      -0.4969  -0.1760   0.1448            (-----*------)
8      -0.9530  -0.6322  -0.3114  (-----*------)
                                  ---------+---------+---------+---------+
                                        -0.50      0.00      0.50      1.00


Time = 4 subtracted from:

Time     Lower    Center     Upper  ---------+---------+---------+---------+
8      -0.7770  -0.4562  -0.1353      (------*-----)
                                  ---------+---------+---------+---------+
                                        -0.50      0.00      0.50      1.00
```

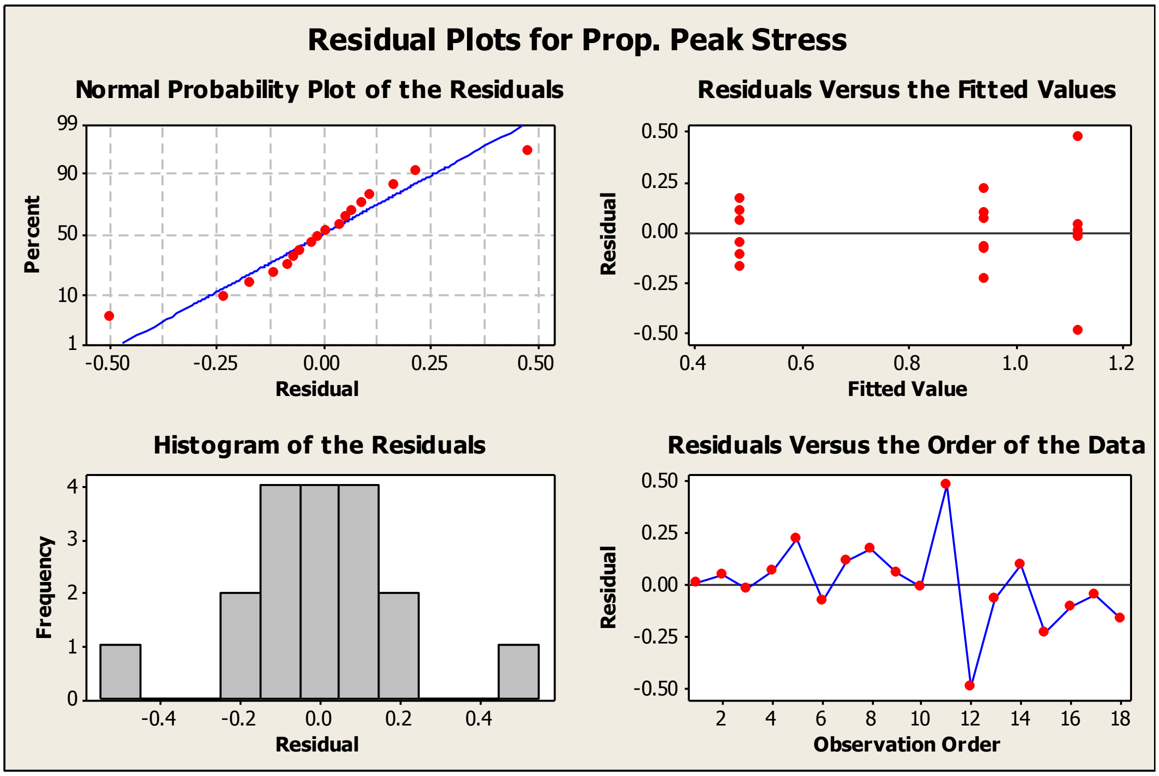

Figure 111: Residual plots for proportional peak stress, material 5

One-way ANOVA: Prop. Peak Stress versus Time for Material 6

```
Source  DF      SS      MS       F      P
Time     2  2.5599  1.2799  112.72  0.000
Error   15  0.1703  0.0114
Total   17  2.7302

S = 0.1066   R-Sq = 93.76%   R-Sq(adj) = 92.93%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev    +---------+---------+---------+---------
```

```
2       6  1.2960  0.1680                                 (--*--)
4       6  0.7254  0.0696                   (--*--)
8       6  0.3816  0.0313    (--*--)
                             +---------+---------+---------+---------
                           0.30      0.60      0.90      1.20

Pooled StDev = 0.1066


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower   Center    Upper  -------+---------+---------+---------+--
4      -0.7302  -0.5706  -0.4109           (---*---)
8      -1.0741  -0.9144  -0.7548  (---*---)
                                  -------+---------+---------+---------+--
                                      -0.80     -0.40     -0.00      0.40


Time = 4 subtracted from:

Time     Lower   Center    Upper  -------+---------+---------+---------+--
8      -0.5035  -0.3438  -0.1842                (---*---)
                                  -------+---------+---------+---------+--
```

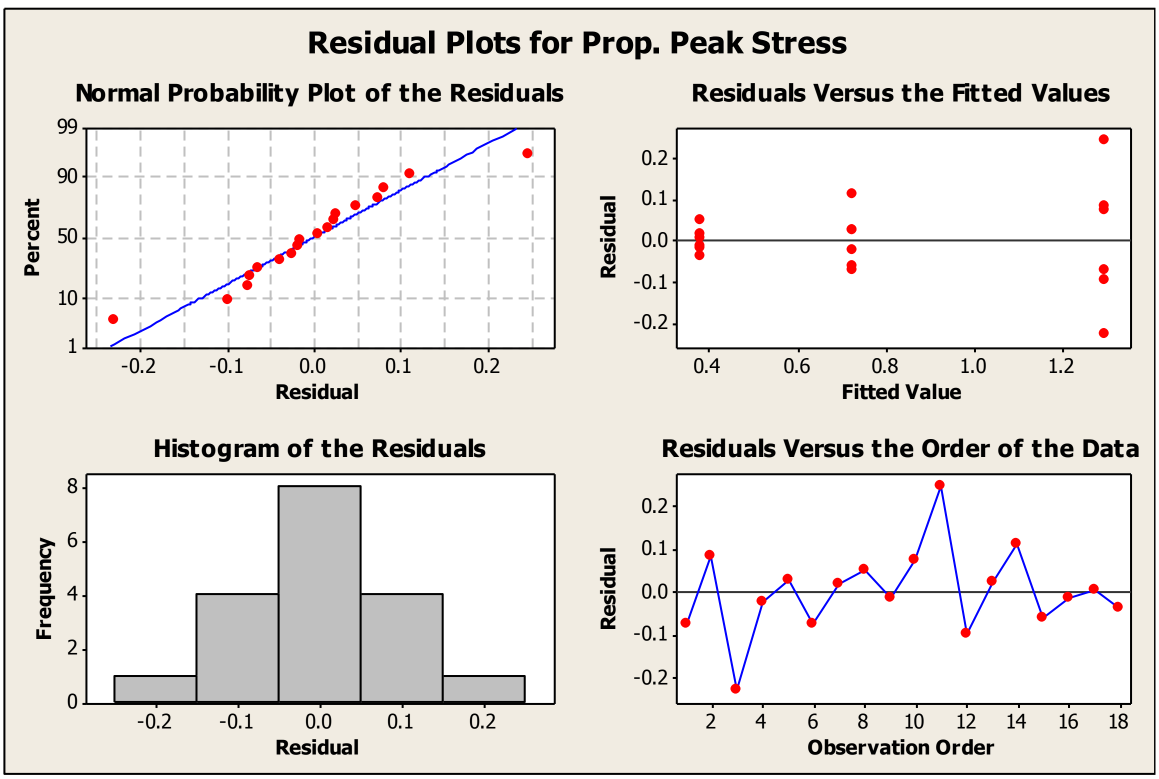

Figure 112: Residual plots for proportional peak stress, material 6

One-way ANOVA: Prop. Peak Stress versus Time for Material 7

```
Source  DF      SS      MS       F      P
Time     2  4.5041  2.2521  196.85  0.000
Error   15  0.1716  0.0114
Total   17  4.6757

S = 0.1070   R-Sq = 96.33%   R-Sq(adj) = 95.84%


                          Individual 95% CIs For Mean Based on Pooled
                          StDev
Level  N    Mean   StDev    +---------+---------+---------+---------
2      6  1.6707  0.1219                                     (--*-)
4      6  0.8992  0.1114                 (--*-)
8      6  0.4605  0.0839    (--*--)
                            +---------+---------+---------+---------
                          0.35      0.70      1.05      1.40

Pooled StDev = 0.1070


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper  -------+---------+---------+---------+--
4     -0.9317  -0.7715  -0.6112          (---*--)
8     -1.3704  -1.2101  -1.0499  (--*--)
                                 -------+---------+---------+---------+--
                                     -1.00     -0.50      0.00      0.50


Time = 4 subtracted from:

Time    Lower   Center    Upper  -------+---------+---------+---------+--
8     -0.5989  -0.4387  -0.2784                 (--*--)
                                 -------+---------+---------+---------+--
                                     -1.00     -0.50      0.00      0.50
```

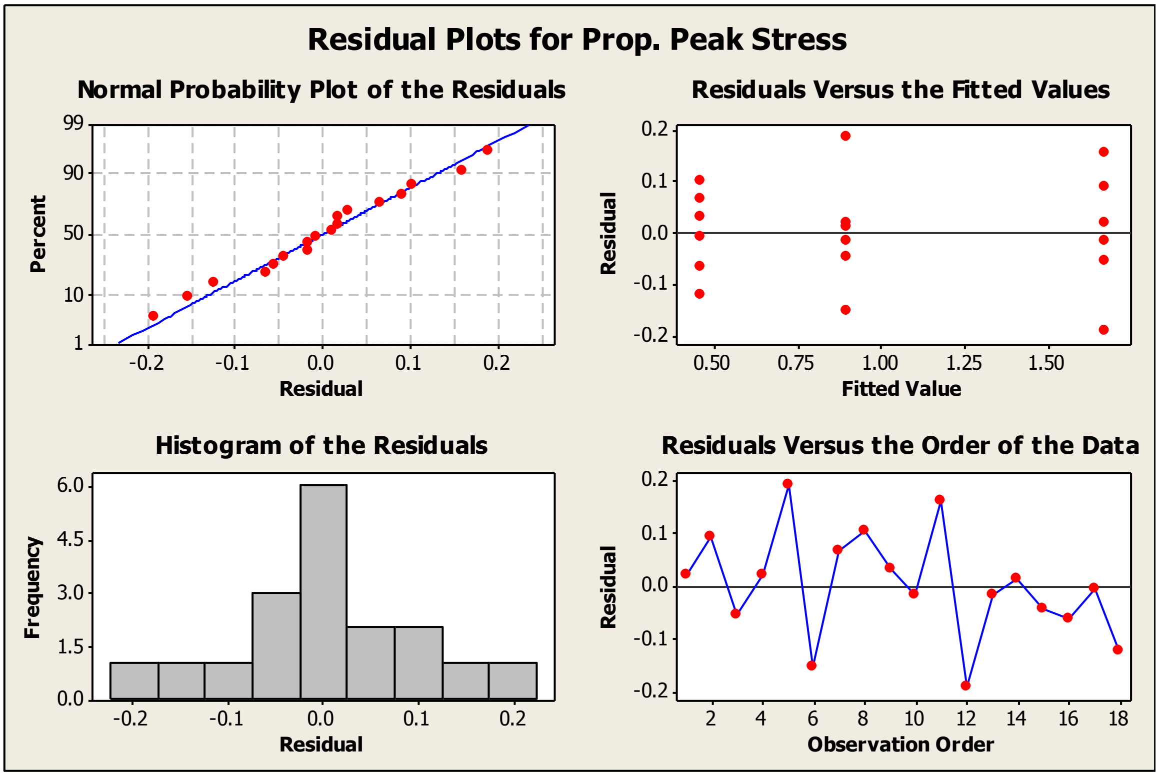

Figure 113: Residual plots for proportional peak stress, material 7

One-way ANOVA: Prop. Peak Stress versus Time for Material 8

```
Source  DF      SS      MS      F      P
Time     2  0.5525  0.2763  27.00  0.000
Error   15  0.1535  0.0102
Total   17  0.7061

S = 0.1012   R-Sq = 78.26%   R-Sq(adj) = 75.36%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -------+---------+---------+---------+--
2      6  0.5682  0.1654                             (-----*----)
4      6  0.3984  0.0457                  (-----*----)
8      6  0.1419  0.0353  (-----*----)
                          -------+---------+---------+---------+--
                               0.16      0.32      0.48      0.64

Pooled StDev = 0.1012


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower    Center     Upper   ---+---------+---------+---------+------
4      -0.3214  -0.1698  -0.0182              (-----*-----)
8      -0.5778  -0.4262  -0.2747   (-----*-----)
                                     ---+---------+---------+---------+------
                                     -0.50     -0.25      0.00      0.25


Time = 4 subtracted from:

Time     Lower    Center     Upper   ---+---------+---------+---------+------
8      -0.4080  -0.2564  -0.1049           (-----*-----)
                                     ---+---------+---------+---------+------
                                     -0.50     -0.25      0.00      0.25
```

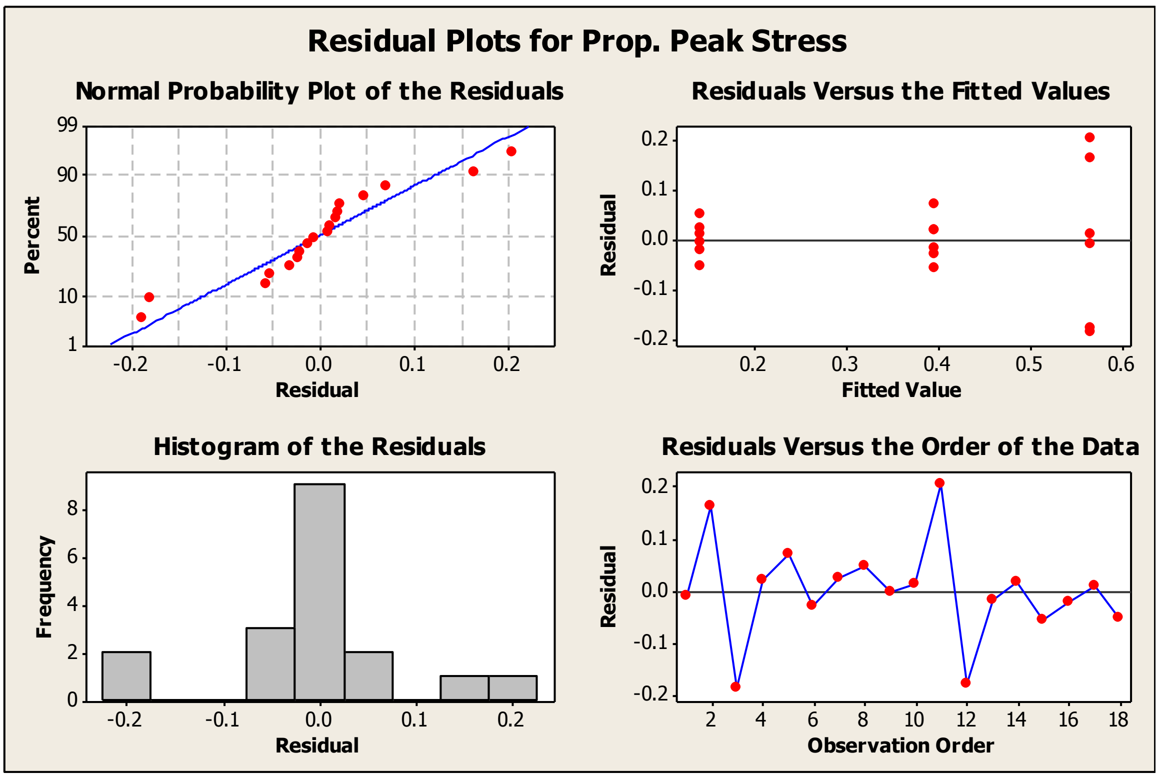

Figure 114: Residual plots for proportional peak stress, material 8

One-way ANOVA: Prop. Peak Stress versus Time for Material 9

```
Source  DF      SS      MS      F      P
Time     2  1.6085  0.8043  37.26  0.000
Error   15  0.3238  0.0216
Total   17  1.9323

S = 0.1469   R-Sq = 83.24%   R-Sq(adj) = 81.01%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
```

```
Level  N    Mean   StDev  --------+---------+---------+---------+-
2      6  0.9133  0.1349                              (-----*----)
4      6  0.6144  0.2021                  (-----*----)
8      6  0.1850  0.0755  (----*-----)
                          --------+---------+---------+---------+-
                               0.25      0.50      0.75      1.00

Pooled StDev = 0.1469


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper  ----+---------+---------+---------+-----
4     -0.5190  -0.2989  -0.0788             (-----*----)
8     -0.9485  -0.7283  -0.5082  (-----*----)
                                 ----+---------+---------+---------+-----
                                  -0.80     -0.40     -0.00      0.40


Time = 4 subtracted from:

Time    Lower   Center    Upper  ----+---------+---------+---------+-----
8     -0.6496  -0.4295  -0.2093          (----*-----)
                                 ----+---------+---------+---------+-----
                                  -0.80     -0.40     -0.00      0.40
```

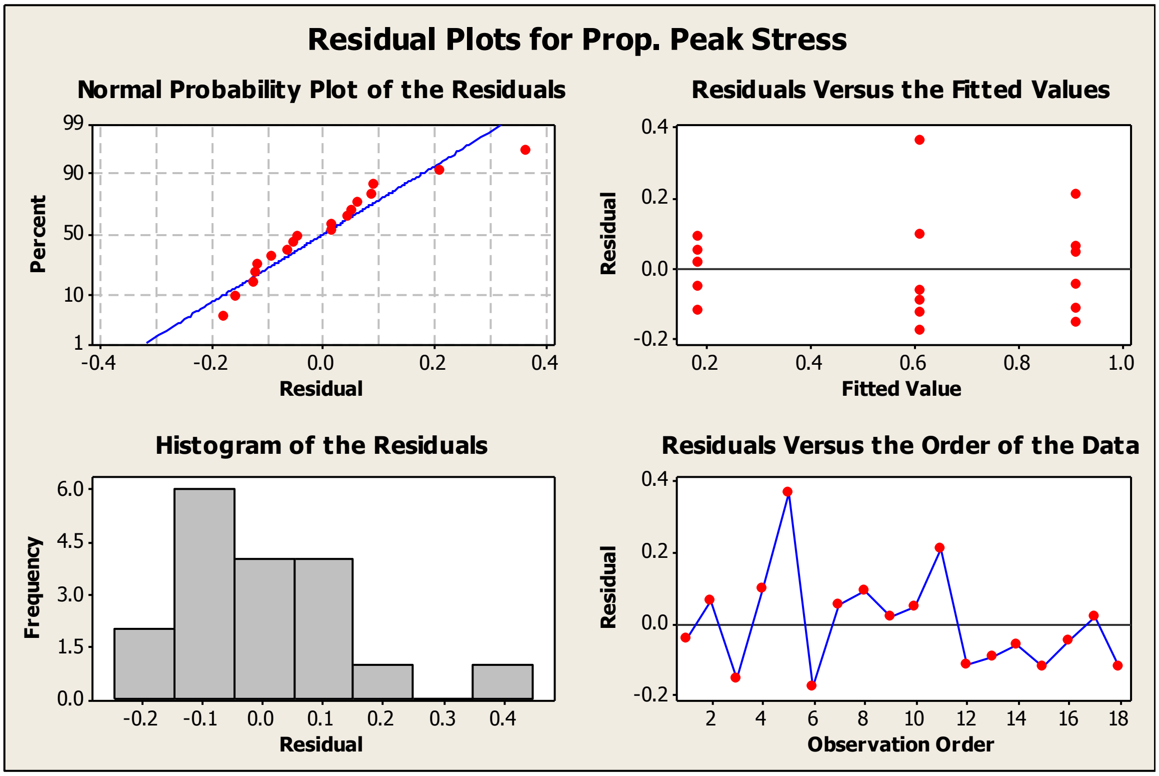

Figure 115: Residual plots for proportional peak stress, material 9

One-way ANOVA: Prop. Peak Stress versus Time for Material 10

Source	DF	SS	MS	F	P
Time	2	1.19357	0.59678	177.84	0.000
Error	15	0.05033	0.00336		
Total	17	1.24390			

S = 0.05793   R-Sq = 95.95%   R-Sq(adj) = 95.41%

```
                                   Individual 95% CIs For Mean Based on
                                   Pooled StDev
Level  N     Mean    StDev   -+---------+---------+---------+--------
2      6  0.85407  0.05463                                (--*-)
4      6  0.60734  0.06882                    (-*--)
8      6  0.22798  0.04844   (-*--)
                             -+---------+---------+---------+--------
                           0.20      0.40      0.60      0.80
```

Pooled StDev = 0.05793

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%

```
Time = 2 subtracted from:

Time      Lower    Center     Upper  ----+---------+---------+---------+-----
4      -0.33352  -0.24673  -0.15993                (--*--)
8      -0.71288  -0.62609  -0.53930  (--*--)
                                     ----+---------+---------+---------+-----
                                      -0.60     -0.30      0.00      0.30


Time = 4 subtracted from:

Time      Lower    Center     Upper  ----+---------+---------+---------+-----
8      -0.46616  -0.37937  -0.29257           (--*--)
                                     ----+---------+---------+---------+-----
                                      -0.60     -0.30      0.00      0.30
```

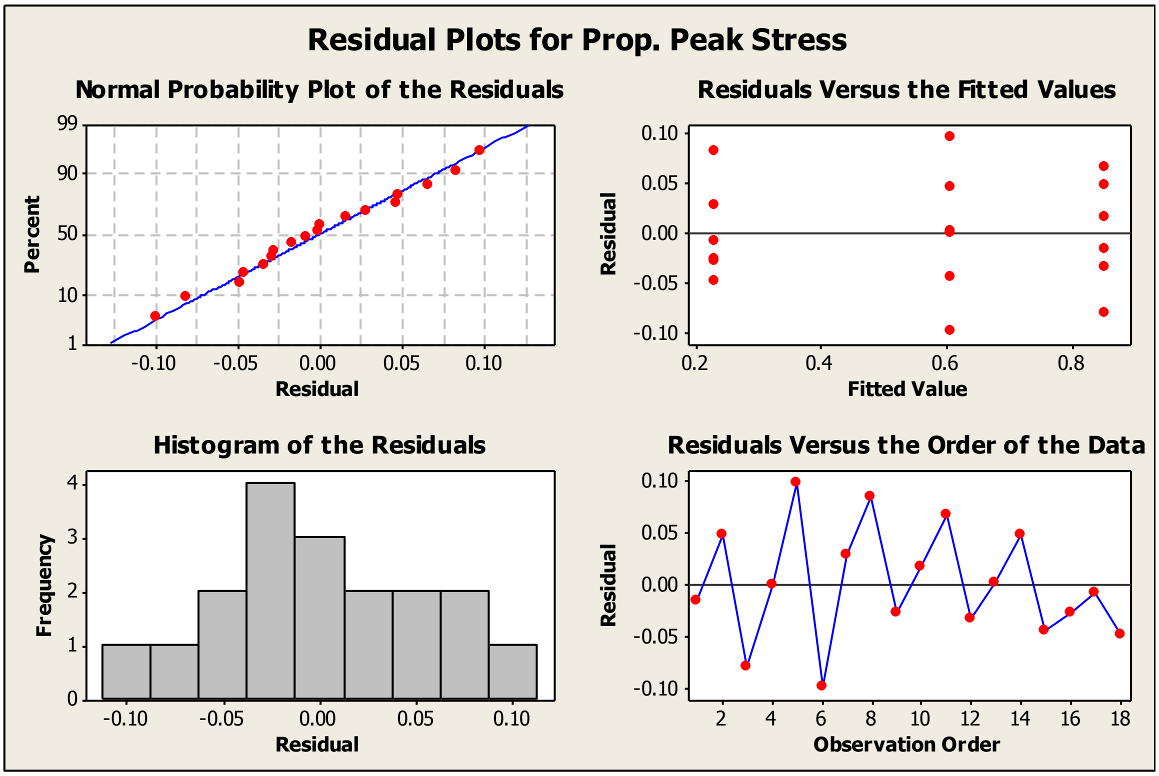

Figure 116: Residual plots for proportional peak stress, material 10

One-way ANOVA: Prop. Peak Stress versus Time for Material 11

```
Source  DF       SS       MS       F      P
Time     2  0.97059  0.48529  127.34  0.000
Error   15  0.05717  0.00381
Total   17  1.02775

S = 0.06173   R-Sq = 94.44%   R-Sq(adj) = 93.70%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev    +---------+---------+---------+---------
```

```
2       6  0.82045  0.05209                                        (--*--)
4       6  0.60027  0.08948                             (--*--)
8       6  0.25617  0.02672    (--*-)
                               +---------+---------+---------+---------
                             0.20      0.40      0.60      0.80

Pooled StDev = 0.06173


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time      Lower    Center     Upper   --+---------+---------+---------+-------
4      -0.31268  -0.22018  -0.12769              (--*--)
8      -0.65677  -0.56428  -0.47179   (--*--)
                                      --+---------+---------+---------+-------
                                     -0.60     -0.30      0.00      0.30


Time = 4 subtracted from:

Time      Lower    Center     Upper   --+---------+---------+---------+-------
8      -0.43659  -0.34410  -0.25160         (---*--)
                                      --+---------+---------+---------+-------
                                     -0.60     -0.30      0.00      0.30
```

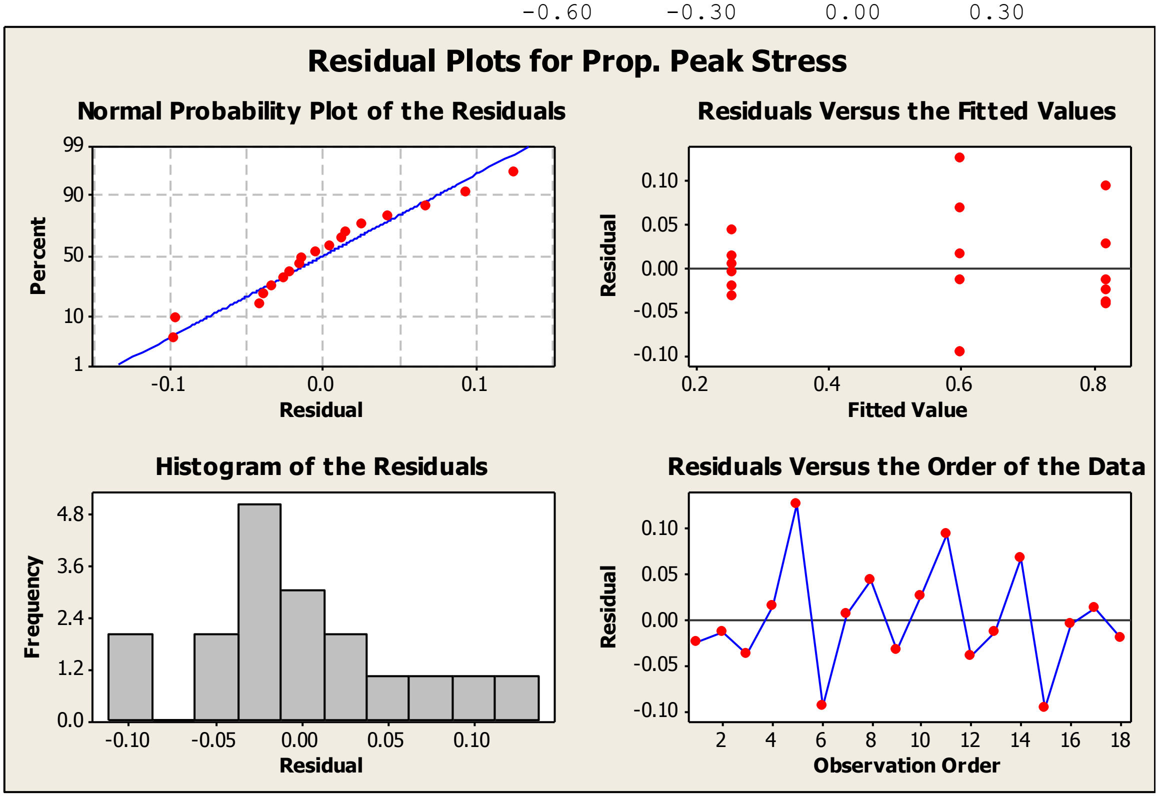

Figure 117: Residual plots for proportional peak stress, material 11

One-way ANOVA: Prop. Peak Stress versus Time for Material 12

```
Source  DF       SS       MS      F      P
Time     2  1.22205  0.61103  98.27  0.000
Error   15  0.09327  0.00622
Total   17  1.31532

S = 0.07885   R-Sq = 92.91%   R-Sq(adj) = 91.96%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  --------+---------+---------+---------+-
2      6  0.75511  0.08028                                  (---*--)
4      6  0.46201  0.09389                   (--*---)
8      6  0.11756  0.05825  (---*--)
                            --------+---------+---------+---------+-
                                 0.20      0.40      0.60      0.80

Pooled StDev = 0.07885


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower    Center     Upper   --+---------+---------+--------+-------
4     -0.41125  -0.29310  -0.17496             (---*--)
8     -0.75570  -0.63755  -0.51941   (---*--)
                                     --+---------+---------+--------+-------
                                    -0.70     -0.35      0.00      0.35


Time = 4 subtracted from:

Time     Lower    Center     Upper   --+---------+---------+--------+-------
8     -0.46259  -0.34445  -0.22631            (--*---)
                                     --+---------+---------+--------+-------
                                    -0.70     -0.35      0.00      0.35
```

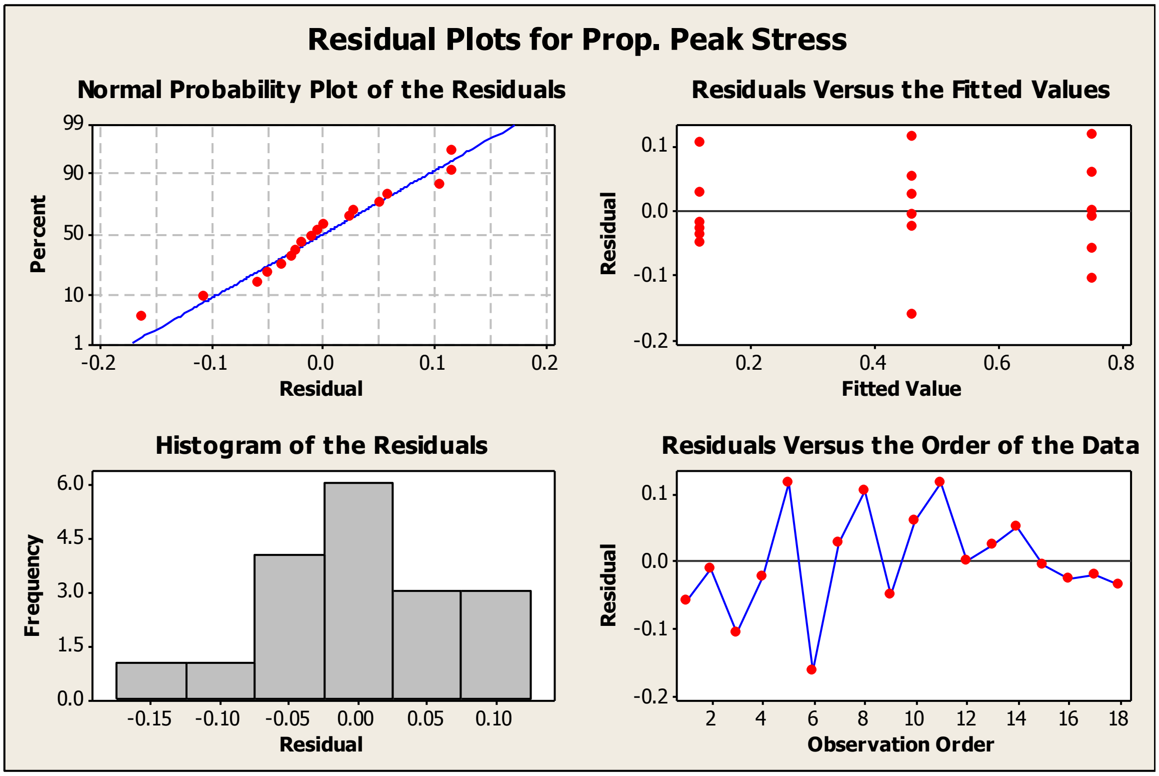

Figure 118: Residual plots for proportional peak stress, material 12

One-way ANOVA: Prop. Peak Stress versus Time for Material 13

```
Source  DF       SS       MS       F      P
Time     2  1.34169  0.67085  100.72  0.000
Error   15  0.09991  0.00666
Total   17  1.44160

S = 0.08161   R-Sq = 93.07%   R-Sq(adj) = 92.15%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  -----+---------+---------+---------+----
2      6  0.87432  0.07114                             (--*--)
4      6  0.58145  0.11635               (--*--)
8      6  0.20722  0.03720  (--*--)
                            -----+---------+---------+---------+----
                               0.25      0.50      0.75      1.00

Pooled StDev = 0.08161


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time      Lower    Center     Upper  ---+---------+---------+---------+------
4      -0.41515  -0.29287  -0.17060              (---*--)
8      -0.78938  -0.66710  -0.54482  (---*--)
                                     ---+---------+---------+---------+------
                                     -0.70     -0.35      0.00      0.35


Time = 4 subtracted from:

Time      Lower    Center     Upper  ---+---------+---------+---------+------
8      -0.49651  -0.37423  -0.25195            (--*---)
                                     ---+---------+---------+---------+------
                                     -0.70     -0.35      0.00      0.35
```

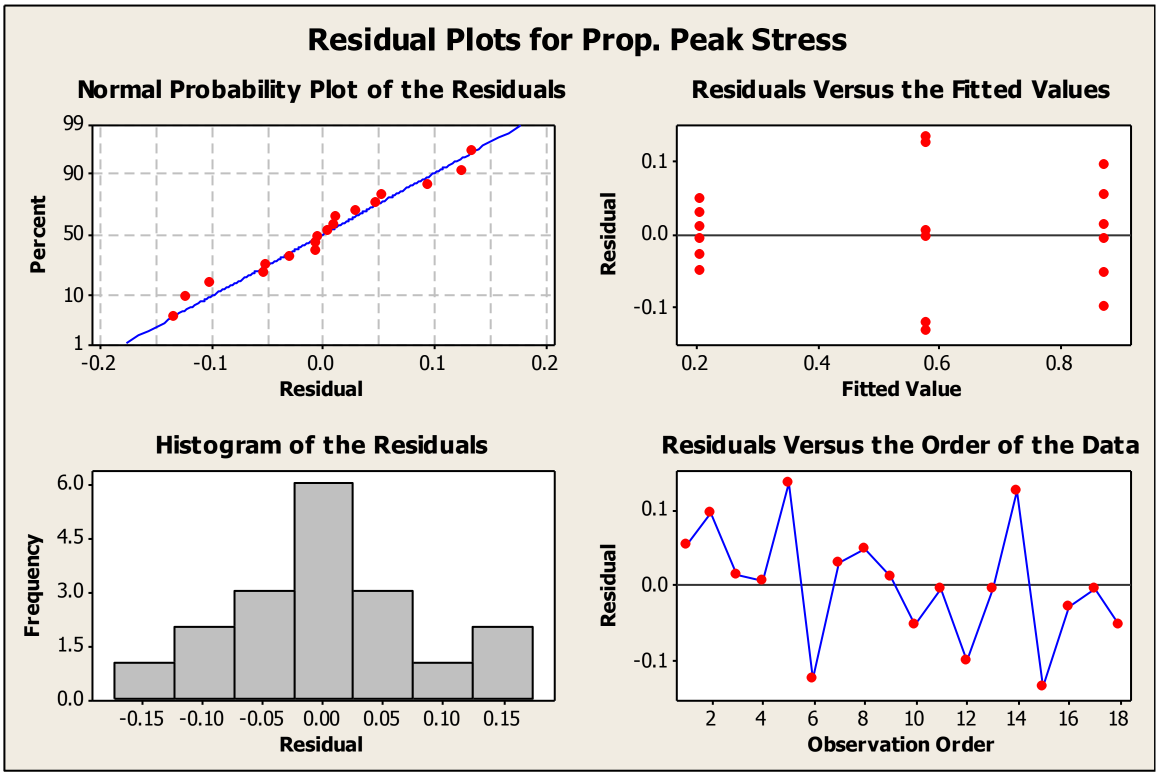

Figure 119: Residual plots for proportional peak stress, material 13

One-way ANOVA: Prop. Peak Stress versus Time for Material 14

```
Source  DF       SS       MS      F      P
Time     2  0.21132  0.10566  39.93  0.000
Error   15  0.03969  0.00265
Total   17  0.25101

S = 0.05144   R-Sq = 84.19%   R-Sq(adj) = 82.08%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev    +---------+---------+---------+---------
```

```
2       6  0.76257  0.03602                           (---*----)
4       6  0.78662  0.06224                             (----*---)
8       6  0.54570  0.05260    (----*---)
                              +---------+---------+---------+---------
                            0.50      0.60      0.70      0.80

Pooled StDev = 0.05144


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time      Lower    Center     Upper     +---------+---------+---------+---------
4      -0.05302   0.02405   0.10112                      (----*---)
8      -0.29395  -0.21688  -0.13981       (---*----)
                                        +---------+---------+---------+---------
                                     -0.32     -0.16      0.00      0.16


Time = 4 subtracted from:

Time      Lower    Center     Upper     +---------+---------+---------+---------
8      -0.31800  -0.24093  -0.16385     (----*----)
                                        +---------+---------+---------+---------
                                     -0.32     -0.16      0.00      0.16
```

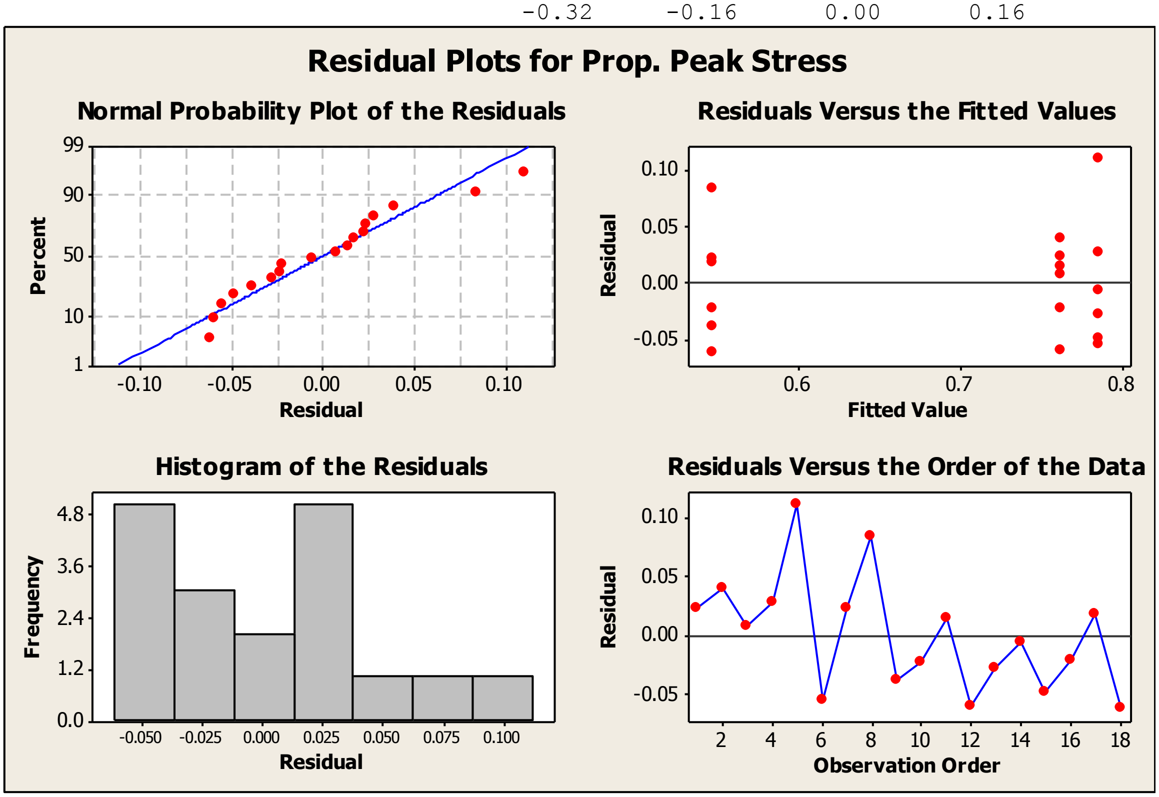

Figure 120: Residual plots for proportional peak stress, material 14

One-way ANOVA: Prop. Peak Stress versus Time for Material 15

```
Source  DF       SS       MS     F      P
Time     2  0.12148  0.06074  9.16  0.003
Error   15  0.09947  0.00663
Total   17  0.22095

S = 0.08143   R-Sq = 54.98%   R-Sq(adj) = 48.98%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  -----+---------+---------+---------+----
2      6  0.91815  0.05252                      (------*------)
4      6  0.81399  0.10724           (------*------)
8      6  0.71696  0.07507  (------*------)
                            -----+---------+---------+---------+----
                               0.70      0.80      0.90      1.00

Pooled StDev = 0.08143


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time     Lower    Center     Upper   --+---------+---------+---------+-------
4     -0.22617  -0.10416   0.01785          (-------*-------)
8     -0.32319  -0.20118  -0.07917   (--------*-------)
                                     --+---------+---------+---------+-------
                                    -0.30     -0.15      0.00      0.15


Time = 4 subtracted from:

Time     Lower    Center    Upper   --+---------+---------+---------+-------
8     -0.21903  -0.09702  0.02499          (--------*-------)
                                    --+---------+---------+---------+-------
                                   -0.30     -0.15      0.00      0.15
```

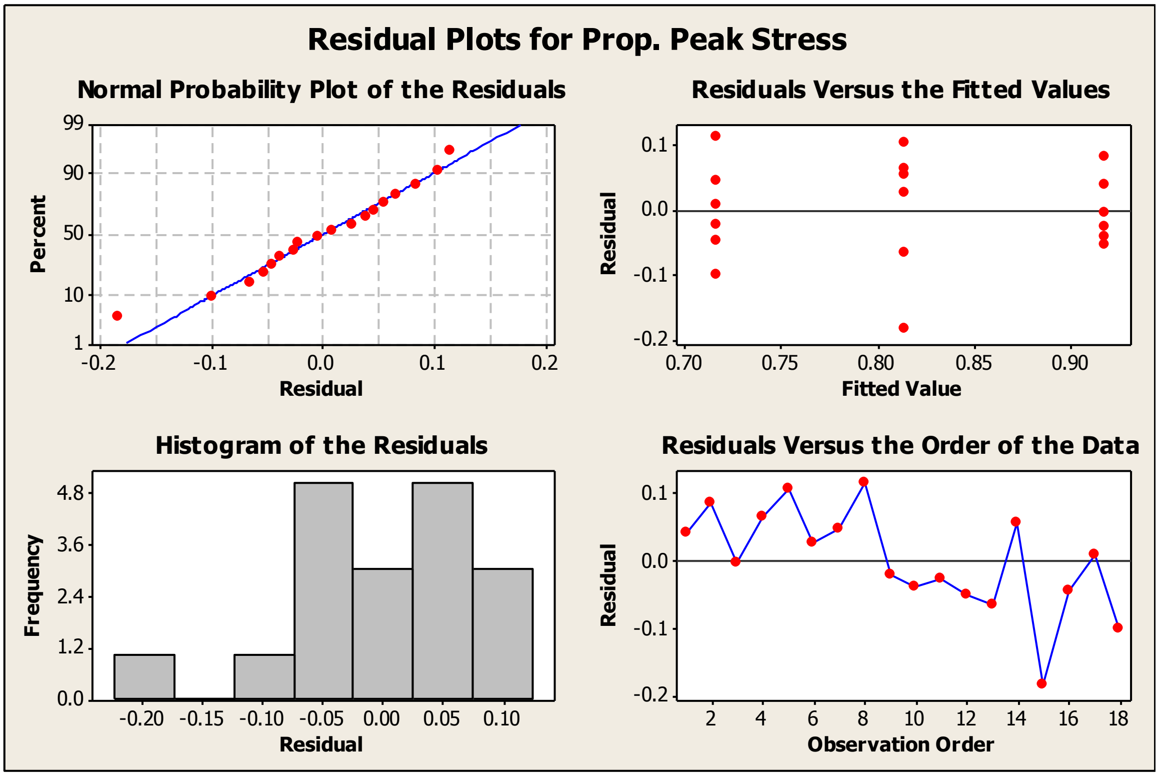

Figure 121: Residual plots for proportional peak stress, material 15

One-way ANOVA: Prop. Peak Stress versus Time for Material 16

```
Source  DF      SS      MS      F      P
Time     2  0.8612  0.4306  13.59  0.000
Error   15  0.4752  0.0317
Total   17  1.3363

S = 0.1780   R-Sq = 64.44%   R-Sq(adj) = 59.70%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev  -----+---------+---------+---------+----
2      6  1.0648  0.1972                      (------*-----)
4      6  0.8703  0.1526               (-----*-----)
8      6  0.5352  0.1813  (-----*------)
                          -----+---------+---------+---------+----
                             0.50      0.75      1.00      1.25

Pooled StDev = 0.1780


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%
```

```
Time = 2 subtracted from:

Time     Lower   Center    Upper  ---+---------+---------+---------+------
4      -0.4612  -0.1945   0.0721            (------*-------)
8      -0.7963  -0.5296  -0.2629  (-------*------)
                                  ---+---------+---------+---------+------
                                  -0.70     -0.35      0.00      0.35


Time = 4 subtracted from:

Time     Lower   Center    Upper  ---+---------+---------+---------+------
8      -0.6017  -0.3351  -0.0684        (------*-------)
                                  ---+---------+---------+---------+------
                                  -0.70     -0.35      0.00      0.35
```

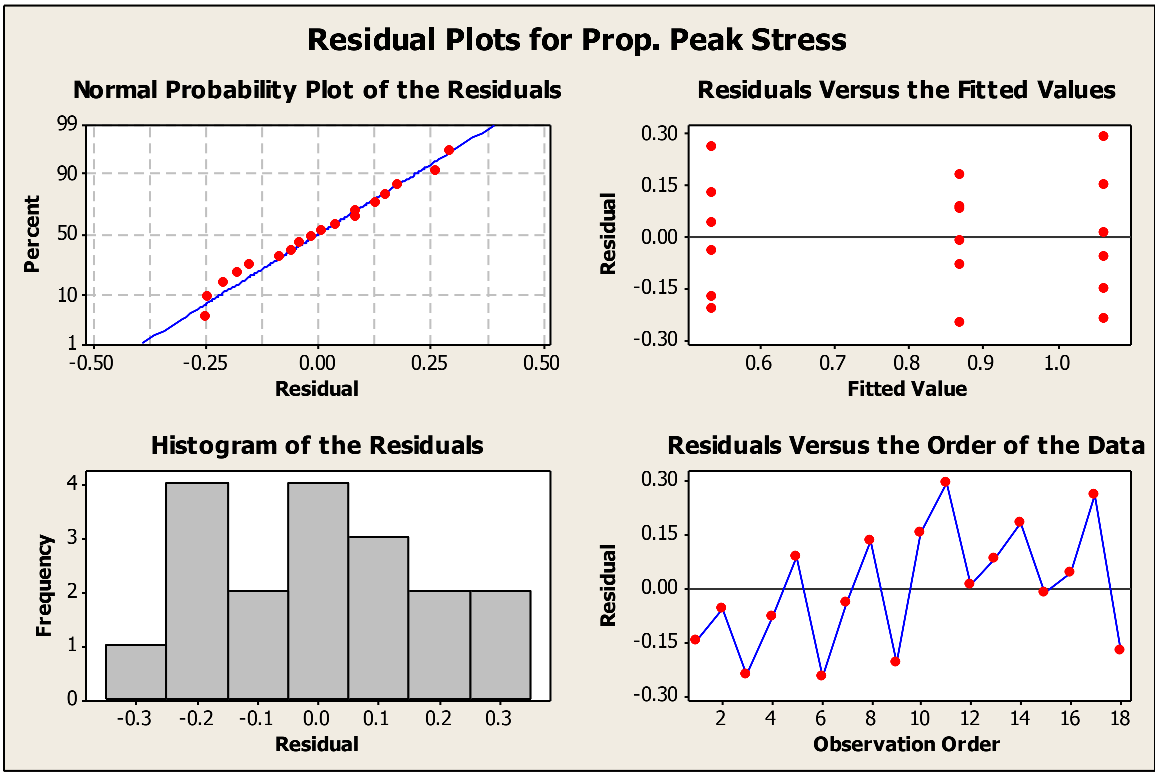

Figure 122: Residual plots for proportional peak stress, material 16

One-way ANOVA: Prop. Peak Stress versus Time for Material 17

```
Source  DF      SS      MS     F      P
Time     2  0.3661  0.1831  7.37  0.006
Error   15  0.3725  0.0248
Total   17  0.7387

S = 0.1576   R-Sq = 49.57%   R-Sq(adj) = 42.84%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
```

```
Level  N    Mean   StDev  ---------+---------+---------+---------+
2      6  0.9564  0.1342                     (--------*--------)
4      6  0.9005  0.2182                  (-------*--------)
8      6  0.6298  0.0942  (-------*--------)
                          ---------+---------+---------+---------+
                                0.64      0.80      0.96      1.12

Pooled StDev = 0.1576


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 97.97%


Time = 2 subtracted from:

Time    Lower   Center    Upper  ---------+---------+---------+---------+
4     -0.2921  -0.0560   0.1802           (-------*-------)
8     -0.5627  -0.3266  -0.0905  (-------*-------)
                                 ---------+---------+---------+---------+
                                       -0.30      0.00      0.30      0.60


Time = 4 subtracted from:

Time    Lower   Center    Upper  ---------+---------+---------+---------+
8     -0.5068  -0.2707  -0.0345    (-------*-------)
                                 ---------+---------+---------+---------+
                                       -0.30      0.00      0.30      0.60
```

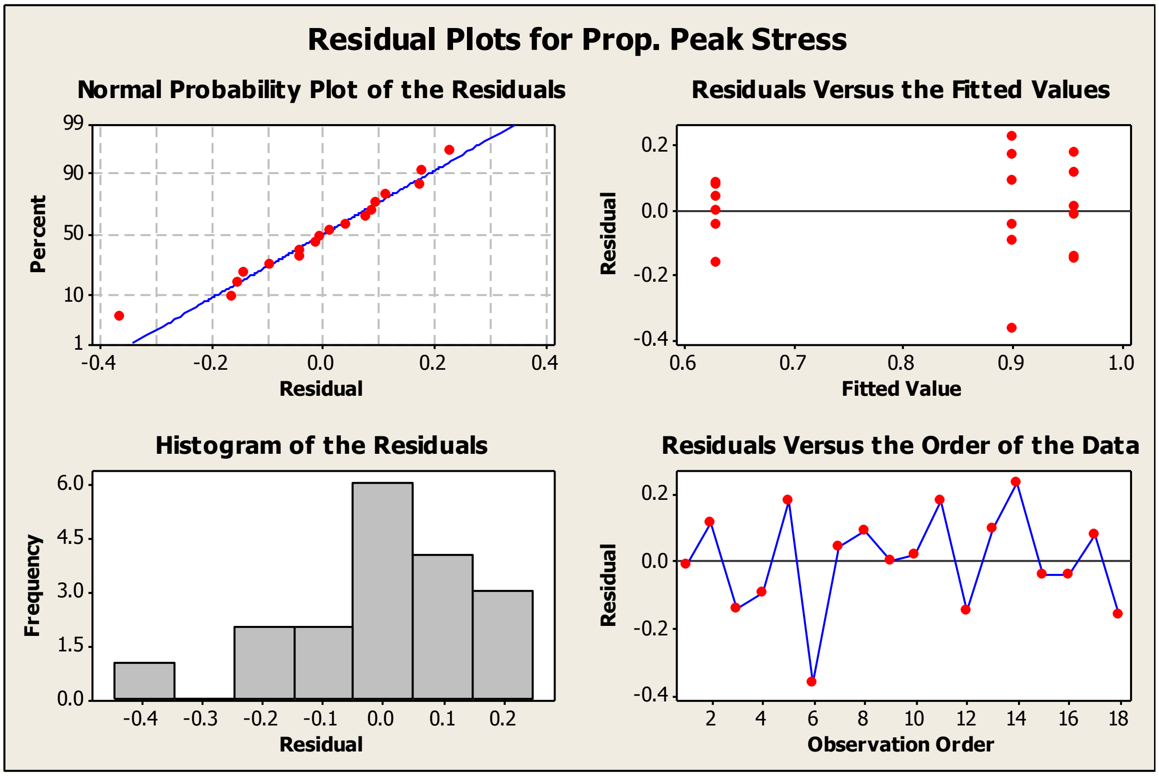

Figure 123: Residual plots for proportional peak stress, material 17