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Starch Resin Moisture Level Effect on Injection Molding Processability and Molded Part Mechanical Properties with Pure Starch Resin and Polymer Blends

Jordan Mark Ellingson

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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School of Technology

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ABSTRACT

Starch Resin Moisture Level Effect on Injection Molding Processability and Molded Part Mechanical Properties with Pure Starch Resin and Polymer Blends

Jordan Ellingson
School of Technology, BYU
Master of Science

The current and forecasted global consumption of plastic packaging and products through the 21st century combined with the already reported and growing negative impact of plastics on the environment due to plastics being synthesized from nonrenewable resources that do not biodegrade is of serious concern. However, recent advances in starch technology including the development of thermoplastic starch (TPS) materials —polymers that are both renewable and biodegradable—have brought hope to reducing this impact. The mechanical properties of thermoplastic starch have often been improved by blending with synthetic polymers. One issue that arises with blending is volatilization of the melt from moisture in the TPS materials.

Ecostarch™, a proprietary, pelletized thermoplastic starch resin formulated from potato starch, was processed and tested to observe injection molding processability at various moisture levels, in pure TPS as well as various blend ratios with high-density polyethylene (HDPE) and polypropylene (PP). This study evaluated and analyzed the effects of the TPS pellet moisture content on void formation in the plastic pre-injection melt and subsequent molded part mechanical properties. Statistical analysis of the test results showed that moisture had a significant effect on void formation in the plastic melt. In TPS/HDPE blends, voids percent (as measured by cross section area) increased by 300-350% from 0.6% to 1.4% moisture levels. In unblended TPS, void percent increased by 150% from 0.4% to 1.4% moisture levels. In the unblended TPS parts, impact strength (energy in ft-lb) was decreased by 1% from 0.6% to 1.4% moisture level. In the TPS/HDPE and TPS/PP blends, there was no significant effect on impact strength due to the moisture percent levels of the TPS. Modulus decreased by 25% from 0.4% to 1.4% moisture level in unblended TPS parts. From 0.6% to 1.4% change in TPS moisture content, the modulus of the TPS/HDPE blend decreased by 9% at a 30% TPS/70% HDPE blend and decreased by 14% at a 70% TPS/30% HDPE blend. Though the moisture of TPS did not have a significant impact on the tensile strength of TPS/HDPE blends, the tensile strength of TPS/PP blend samples were significantly affected: a change from 0.6% to 1.4% moisture increased tensile strength 34% at a 70% TPS/30% PP blend and increased tensile strength by 22% at a 30% TPS/70% PP blend.

Thus the results of this study highlight the relationships between moisture, voids, and mechanical performance of TPS and TPS/Polymer blends.

Keywords: Jordan Mark Ellingson, thermoplastic starch, TPS, Ecostarch, injection mold, voids, BiologiQ, tensile test, impact test, glycerol, moisture content, polyolefin

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1 INTRODUCTION

1.1 Background

Plastic is an integral part of our every-day lives. In 2010, the US produced over 31 million tons of plastic waste—or 12% of overall waste (EPA 2012). Experts estimate a 2- or 3-fold global increase in plastics consumption during the beginning of the 21st century due to growth in developing countries (Rudnik 2008). The alarming accumulation of plastic waste is compounded by the fact that it is synthesized from non-renewable resources, and it is considered "indestructible" when exposed to natural forces of decomposition (Carvalho 2008). To avoid these issues, researchers have turned their attention to the feasibility of producing plastic goods that are more friendly to the environment—both in their synthesis (through the use of renewable resources) and in their disposal (through their ability to completely or partially decompose through natural means). Known as *green plastics* (Gerngross 2000), *biodegradable polymers* (Moore and Saunders 1997), or *compostable polymers* (Rudnik 2008), these products can be made both from petroleum-based resources such as poly(caprolactone) (PCL) or poly(vinyl alcohol) (PVA). Fortunately, scientists have discovered ways to produce compostable polymers from renewable resources such as poly(lactic acid) (PLA) and thermoplastic starch (TPS) (Rudnik 2008).

This research focuses on a specific type of TPS derived from potato starch. More specifically, the material examined in this study is a proprietary form of pelletized TPS, designed for injection molding and extrusion processing applications. Despite the environmental benefits of using thermoplastic derived from potato starch, this material presents unique challenges due to its naturally high moisture content, which can cause bubble formation during processing due to water volatilization.

1.2 **Objective**

The purpose of this research is to determine to what extent the moisture content of thermoplastic potato starch affects the resin's mechanical properties in injection-molded parts when operated at constant standard operating parameters (temperature, shot size, feed rate, etc). This research aims to determine the above-mentioned relationship by observing the presence and character of undesirable voids in the melt of extrudate leaving the nozzle of the injection mold machine in addition to completed parts. To ensure an industrially-relevant understanding of the effects of moisture of the thermoplastic potato starch, the research includes observations for both stand-alone TPS resin and TPS/polymer blends.

1.3 **Problem Statement**

Although researchers have identified the importance of water as a plasticizer in the formation of TPS, it has been observed that too much moisture can cause processing difficulties due to bubble formation from steam (Liu, et al. 2009). This is a problem faced by Idaho start-up, BiologiQ, Inc., when processing its trademarked and patented Ecostarch™ resin (a potato-based, pelletized TPS resin) in injection molding applications.

A clear understanding of the relationship between the level of moisture and the resulting bubble formation and mechanical performance of finished parts in the injection molding process will help lead to greater process optimization for large-scale operations using TPS—both for

BiologiQ and for other industry players. By manipulating moisture content of the thermoplastic potato starch resin, this research will possibly help define ideal processing practices that reach beyond the technique of minimizing the resin's exposure to atmospheric moisture.

This study additionally considers the effects of moisture on different TPS/polymer blends, since a potential application of thermoplastic potato starch resin is its use as a blended ingredient with common polymers. After all, TPS is rarely used alone, due to its poor mechanical properties. Instead it is often blended with synthetic polymers to improve its mechanical performance (Liu, et al. 2009).

1.4 **Justification**

This research is justified by the fact that TPS presents a high-potential alternative to petroleum-based polymers due to the fact that it is derived from a renewable source and that it is biodegradable. The aim of this research is to address the problem of water volatilization which can hinder the industrial adoption of this product.

1.5 **Hypotheses**

The first hypothesis of this research involves the observable volatilization of moisture found in TPS. The stated hypothesis is: *The level of moisture content of the TPS resin has an effect on the size and number of voids in the melt of an injection-molded part.*

A second hypothesis closely relates to the first regarding the way voids in the melt translate to voids in the injection-molded part. The second stated hypothesis is: *Voids within the injection-molded part are directly related to the amount of voids in the melt.*

An additional hypothesis of the research involves the effects of moisture content on the final injection-molded part, as pertaining to its performance: *The level of moisture content of the TPS resin has an effect on the tensile and impact performance of injection-molded samples.*

1.6 **Methodology**

Unblended TPS resin was processed in an injection molding machine at various moisture content levels. Additionally, two different polymers (HDPE and PP) were blended with the TPS at various moisture content levels and blend ratios. The above-stated hypotheses were tested by means of microscope for void detection and by mechanical testing of injection-molded parts. The mechanical tests consisted of tensile testing and falling dart impact testing. The independent variables of moisture content and polymer blend were tested for effect using statistical regression analysis.

1.7 **Definition of Terms**

Ecostarch™ Resin (ESR) – This is a patented TPS compound produced by BiologiQ™, Inc., based in Idaho, USA. Ecostarch ™ is made from potato starch, mixed with 27 percent weight content of glycerol, which acts as a plasticizer. The MSDS and technical data sheets for this material are not yet available. However, Appendix F does include these sheets for a similar TPS product from BiologiQ, Inc., which is produced with 2 percent less glycerol.

Extrudate -- This term is used interchangeably with the word, “melt.” Though this study does not use any extruder equipment, some melted plastic material was tested after allowing it to be extruded from the injection molding machine nozzle while backed away from the sprue bushing.

Gelatinization – Gelatinization is defined as the process of destroying the starch's crystalline structure through molecular solubilization. This can occur when starch is exposed to excess water and elevated temperatures. However, gelatinization occurs more rapidly when sheer forces are added—such as the force of an extruder screw (Liu, et al. 2009). Without the aid of a plasticizer, the gelatinization temperature of starch is higher than its thermal degradation temperature, making it impossible to create TPS without the aid of a plasticizer (Wiedmann and Strobel 1991).

Glycerol – Commonly referred to as glycerin, this material acts as a plasticizer or gelatinization agent in thermoplastic starch. Though water is the most common plasticizer used in TPS, it is also less practical due to the resulting poor mechanical properties in water-gelatinized TPS (Liu, et al. 2009). Glycerol is a common plasticizer used to improve TPS properties.

High-density Polyethylene (HDPE) – This is a common thermoplastic material known for its low reactivity, high strength and toughness, and its relatively low processing temperatures.

Moisture Content (MC) – For the purposes of this research, MC refers to the percentage of water contained in the TPS, as measured by weight.

Plasticizer – A plasticizer is a material added to a polymer to give it certain properties. It is often used to improve a polymer's melt flow characteristics. In this study, the TPS was plasticized with glycerol (see the definition for *Gelatinization*).

Polyolfin – This term groups polyethylene and polypropylene together. The term's literal meaning is "oil-like," referring to the waxy feel of these polymers. Polyolefins are characterized by the fact that they are made up of only hydrogen and carbon atoms, and that they are non-aromatic (Strong 2006).

Polypropylene (PP) – This is a common thermoplastic material, also known for low reactivity and toughness. It is favored in plastic parts that require moving hinges, thanks to its toughness and lower crystallinity.

Thermoplastic Starch (TPS) -- This material is created from starches derived from plants such as corn, wheat, rice, potato, tapioca, sorghum, arrowroot, and sago (Rudnik 2008) (Whistler, BeMiller and Paschall 1984). Usually in powder form, the starch turns to thermoplastic when combined with a swelling agent such as water, or another plasticizer such as glycerol (Rudnik 2008). According to A. J. F. Carvalho, TPS can be generally defined as a mixture of starch and plasticizer processed by a batch mixer or extruder at temperatures from 140°C to 160°C (Carvalho 2008).

Void – Refers to a small space or opening found in plastic. This study examines the relationship between void formation and moisture content under the hypothesis that voids are created when moisture within the polymer turns to steam and expands to form bubbles or voids. However, this study ignores other possible factors that could lead to void creation (such as glycerol content) by keeping other possible factors constant.

Volatilization – This refers to the creation of steam when water reaches 100ºC.

2 LITERATURE REVIEW

2.1 Introduction

This section will explore published literature regarding the relationships between TPS and moisture content. The literature review begins with a basic explanation of researchers' findings regarding TPS. The review will then narrow its focus to specific background and foundational research pertinent to topics related to this study like potato starch resin, moisture content and testing, extrusion processing of starch, starch/polymer blends, etc.

2.2 Thermoplastic Starch

Starch is a naturally-occurring polymer (or biopolymer) found in a variety of plants such as corn, wheat, rice, potato, tapioca, sorghum, arrowroot, and sago (Rudnik 2008) (Whistler, BeMiller and Paschall 1984). Researchers have discovered ways to transform starch into a thermoplastic--known by researchers as thermoplastic starch, or simply TPS. The advantages of using starch as a polymer include the fact that starch is a cheap and renewable alternative to synthetic polymers (Carvalho 2008).

At first glance, the concept of using starch as a thermoplastic might be counterintuitive. As Mano et al. reports, starch has poor mechanical properties, and it readily degrades at the temperatures typical of thermal processing (Mano, Koniarova and Reis 2003). Additionally, starch has a decomposition temperature that is lower than its melting temperature (Liu, et al. 2008). Fortunately, however, each of these poor characteristics of starch can be countered.

Starch can be "gelatinized" through the aid of a plasticizer at temperatures lower than its decomposition temperature. Gelatinization can be defined as the process of destroying the starch's crystalline structure through molecular solubilization. This can occur when starch is exposed to excess water and elevated temperatures. However, gelatinization occurs more rapidly when sheer forces are added—such as the force of an extruder screw (Liu, et al. 2009). While water is known to be the most effective plasticizer, there are other plasticizers used, depending on the processing technique and desired properties.

Researchers have extensively explored other processing techniques for TPS to achieve desirable material properties and performance for different plastic applications. The poor mechanical properties of native starch have been countered by blending it with synthetic polymers (Griffin 1994). Other processing techniques include adding plasticizers or lubricants, or blending TPS with fibers (Liu, et al. 2009).

2.3 **Injection Molding Thermoplastic Starch**

The application of thermal processing of starch was first developed on the basis of the long-known practice of extrusion cooking for pasta—where the components of mechanical shear force, high temperatures, and water act together to "plasticize" the starchy ingredients (Wiedmann and Strobel 1991). However, these early processes were mostly extrusion applications. In fact, extrusion processing of starch is the most common application of thermoplastic starch (Liu, et al. 2009). Fortunately, extrusion processing is very similar to injection molding, in the sense that both employ the use of a screw to plasticize the polymer through sheer, heat, and pressure.

An example of early innovation in the injection molding of starch products occurred in the mid 1980's when Wittwer and Tomka developed a patent for injection-molded medicine capsules. This product was based on starch in which a moisture content of 5%-30% was specified (Wittwer and Tomka 1987). The process was similar to the traditional extrusion cooking, in the sense that it depended on water as a primary plasticizer.

Researchers have studied ways to counter the negative effects of starch's high viscosity and poor flow properties for injection molding applications. One proven solution is to blend starch with synthetic polymers, which generally lowers the viscosity (Liu, et al. 2009). Another solution is the introduction of an alternative plasticizer such as the glycerol used in the ESR material in this experiment. Rodriguez-Gonzalez, et al. demonstrated that an increase in glycerol content in starch reduces the overall viscosity of the TPS (Rodriguez-Gonzalez, Ramsay and Favis 2004).

Processing conditions have proven to affect physical properties of starch and starch/synthetic polymer blends (Ramkumar, et al. 1996). Therefore, this study sought to minimize the effect of processing conditions by holding them constant across the entire experiment.

2.4 **Pelletized Starch**

In reading researchers' methodologies for injection molding and extrusion of TPS, it seemed that starch is commonly fed into processing equipment in its native form, or in a starch/water (or other plasticizer) mixture, similar to the methodology used by Rodriguez-Gonzalez et al. or Ramkumar et al. (Rodriguez-Gonzalez, Ramsay and Favis 2004) (Ramkumar, et al. 1996). One thing that sets this research apart is the use of pelletized TPS (known as

Ecostarch™ or ESR, and supplied by BioligiQ™), making it possible to process in a short-barrel injection mold machine without the need for additional equipment.

Figure 1: Pelletized Potato TPS Called Ecostarch™

2.5 Starch/ Synthetic Polymer Blends

Starch has long been used as an alternative ingredient in synthetic polymer production. For example, in the 1960's starch was used as an additive or filler in certain polymers like rubber (Griffin, Gelatinized starch based products 1994), LDPE (Griffin, Particulate Starch Based Products 1994), and PVC (Otey and Doane 1984). In 1973, Griffin innovated the use of starch filler in polyethylene films (Griffin, Biodegradable Fillers in Thermoplastics 1973). One obvious advantage to using starch as an additive to petroleum-based polymers is that it reduces consumption of non-renewable resources. Another advantage is the fact that starch is completely biodegradable and/or compostable.

Starch is often blended with synthetic polymers in order to improve the specific physical properties of TPS. For example, starch is highly hydrophilic. However, by blending it with a hydrophobic polymer, the starch/polymer blend becomes less sensitive to moisture (Rudnik 2008). This relationship is investigated in this study. Additionally, starch/synthetic polymer blends have been shown to improve overall the mechanical performance over pure TPS. Rodriguez-Gonzalez et al. illustrated this in finding that PE/TPS blends approach polyethylene-like properties as blend ratio is increased (Rodriguez-Gonzalez, Ramsay and Favis 2004).

2.6 **Effects of Moisture**

Researchers have observed that water acts as the best plasticizer for starch due to its ability to penetrate the starch's crystalline structure (Perry and Donald 2000). The moisture content (MC) of TPS directly affects its viscosity (Liu, et al. 2009). For this reason, Senouci and Smith observed the difficulty of extruding potato starch at low moisture contents in extrusion cooking applications (Senouci and Smith 1986).

Of course there are less volatile options for plasticizers available, such as the glycerol used in ESR (which boils at 554ºF). However, substituting water for other plasticizers like glycerol has the effect of increasing the material's gelatinization temperature (Liu, et al. 2009).

2.6.1 Void Formation and Performance

Mercier and Feillet, in their experimentation with extrusion cooking, described the positive correlation between moisture content of starch and the expansion (or foaming) of the melted starch (due to evaporating water) as it exits the nozzle of the extrusion head. They also determined that the degree of expansion affects the properties of the resulting product (Mercier and Feillet 1975). More recently, manufacturers have taken advantage of the effects of moisture on expansion of starch-based products. For example, Lacourse et al. filed a patent describing an innovative method for preparing biodegradable shaped foam meant to replace polystyrene foam in packaging applications. The patent recommends a moisture content of 21% at processing temperatures above the boiling point of water, 150 to 200 ºC (Lacourse and Altieri 1991).

As illustrated above, the moisture content of starch can easily affect the formation of voids in injection-molding applications. In fact, researchers have repeatedly acknowledged the problem of defects caused by excessive moisture in starch due to the volatile nature of water when raised to the temperatures needed for processing (Griffin 1994). The moisture content in the starch can cause undesirable air bubbles due to expanding steam (Liu, et al. 2009).

Willett and Doane have shown that the tensile properties of starch/poly(hydroxyester ether) composites can be dependent on MC (Willett and Doane 2002). Aside from this study, however, there does not seem to be any research investigating the relationship between moisture, void formation, and mechanical properties.

3 METHODOLOGY

As stated above, the purpose of this research was to identify the effects of moisture on TPS by performing two studies. The first study involved the effects of moisture on void formation within the non-pressurized melt leaving the nozzle of the injection mold machine. The second study involved the effects of moisture on the mechanical performance of injection-molded parts.

3.1 Materials

To determine the effects of moisture on TPS in an injection molding application it was necessary to not only test the TPS as a stand-alone product, but also as a blend with other polymers.

3.1.1 Synthetic Polymers

Two polymers were selected for blending with the TPS: High-density Polyethylene (HDPE) and Polypropylene (PP). These two polyolefin materials were selected due to their favorable properties such as low reactivity, high strength, high toughness, and relatively low processing temperatures. HDPE could also be considered a wise choice for a TPS blend due to its potential application in creating compostable bags or containers. These materials were in the form of standard pellets made for injection molding or extrusion applications. No preparation was needed for the HDPE. However, according to a popular industry reference book, the PP needed to be dried to less than 0.2% moisture content (weight percent) before processing (IDES, Inc. 2004).

3.1.2 TPS

The TPS resin used for this study is called Ecostarch™ resin or ESR. This product is coded as GS270 by the supplier, BiologiQ, Inc., and is supplied in pelletized form. The ESR resin is derived from a blend of potato starch and 27% glycerol, which acts as a plasticizer. Its untreated moisture content at room temperature was about 1.40% ± 0.04 (weight percent).

3.2 **Equipment**

Equipment for this research consisted of machines used for preparing materials, for producing samples, and for testing samples as outlined below.

3.2.1 Preparation Equipment

The primary pieces of equipment used for preparing materials for processing were related to the methods for manipulating and testing for the moisture content of the TPS. An industrial air drier, ARID-X™ Model 35FM, designed for injection-molding applications was used to manipulate the moisture content of the TPS. Prior to processing the TPS, each sample was tested for the level of moisture content by weight percent. For this testing, moisture content was evaluated with a Torbal™ ATS 120 Moisture Analyzer.

Figure 2: ARID-X™ 35FM Air Drier (left) & Torbal™ ATS 120 Moisture Analyzer (right)

3.2.2 Processing Equipment

All injection molding was completed using a 55-ton BOY 50 injection molding machine with a general-purpose screw. The machine was fitted with a mold designed to make Type I tensile testing specimens, conforming to the ASTM D 638-0 standard and falling dart impact testing samples as guided by ASTM Standard D 5628 (ASTM International 2004).

Figure 3: BOY 50M Injection Mold Machine (left) & Mold for Type 1 Tensile and Falling Dart Impact Samples (right)

3.2.3 Testing Equipment

There were three pieces of equipment used for evaluating samples. The first piece of equipment was a Keyence VHX 500 digital microscope, used for evaluating cross-sectional samples of cooled extrudate ejected from the nozzle of the injection mold machine.

Secondly, the Type-I tensile testing specimens were analyzed using a computer-controlled Instron 4204 machine, conforming to ASTM D 638-0 (ASTM International 2004).

The third piece of testing equipment used was an Instron falling dart impact tester, used for gathering data for impact performance of samples, as guided by ASTM Standard D 5628 (ASTM International 2004).

Figure 4: Keyence VHX 500 Microscope (Courtesy of Keyence, Inc. 2013)

Figure 5: Instron 4204 Tensile Testing Machine (left) & Instron Falling Dart Impact Tester (right)

3.3 Experimental Procedure

The methodology for this research consisted of a statistical design of experiments (DOE) with the purpose of challenging the three hypotheses from Chapter 1. Samples of varying moisture and polyolefin blends were analyzed to identify the relationships between moisture content of the TPS and the nature of void formation and mechanical performance.

3.3.1 Design of Experiment

The DOE for this research involved two customized 5^2 Factorial experiments—one for each polyolefin blend—based on a Taguchi L25 Orthogonal array. The decision was made to perform separate experiments for each polyolefin (HDPE and PP) due to the increase in variability of time and processing temperatures when changing over the machine from HDPE to PP or vice versa. In each experiment, the two independent variables were:

- moisture content of TPS (weight percent)
- percentage blend of polyolefin (weight percent)

Samples were created by varying the levels of each independent variable. These samples were measured for four different dependent variables to test for effect. The dependent variables and corresponding tests are outlined in the figure below:

Table 1: Variables Measured and Corresponding Tests

Dependent Variable	Test	ASTM Standard
Young's Modulus	Tensile Test	ASTM D 638
Tensile Strength	Tensile Test	ASTM D 638
Impact Energy	Falling Dart Impact	ASTM Standard D 5628
Cross-sectional Void Area	Microscope	N/A

In each case, all other process constraints (i.e. shot size, barrel temperature, feed rate, etc.) were held constant across all samples, based on the processing conditions recommended for the blended polyolefin, as referenced from “IDES Pocket Specs for Injection Molding.” A third experiment of unblended TPS was performed, by processing the TPS resin at five different moisture levels. Figure 6, below, illustrates the customized 5^2 factorial design, which includes five levels for the moisture % factor, and three levels for the polyolefin blend % factor, resulting in 15 data points from each experiment.

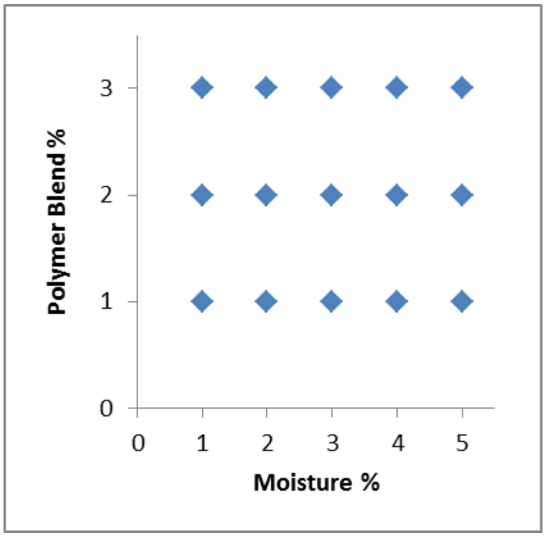


Figure 6: Customized 5^2 Factorial Design of Experiment

3.3.2 Sample Preparation

All moisture content (MC) measurements in this report refer to weight percent.

In order to manipulate MC in the TPS, the ESR resin was placed in the air drier for varying amounts of time. Due to drier variability, the drying time varied too much to create an accurate drying profile for MC versus time. However, maximum and minimum moisture content was established. The maximum moisture content for the resin was established as moisture content of the untreated resin, as shipped, which measured at approximately 1.40 ± 0.04 percent MC. To establish the minimum moisture content, the resin was dried at 250ºF for several hours, until color change was observed (which was interpreted as thermal degradation). The minimum moisture content was around 0.59 ± 0.16 percent MC. The maximum MC and minimum MC were used as two levels in the experiment. The other three MC levels were simply obtained by targeting varying levels of moisture between the maximum and the minimum.

The MC for each sample was analyzed with a Torbal™ ATS 120 Moisture Analyzer. This machine was set to measure the moisture of a 3-gram sample by heating it to 121ºF for 15 minutes. Since drying is a function of batch size, the 15-minute setting was determined to be an optimal drying time for the moisture analyzer when using a 3-gram sample. By using an integrated scale, this machine was capable of interpreting the change in mass attributed to evaporation as the percentage of moisture originally in the sample through the following equation:

$$(m_0 - m)/m_0 \tag{3.1}$$

After obtaining a targeted moisture level of a given batch of TPS, a scale was used to create three different 1-pound batches of TPS/polyolefin blends. The three levels of polymer blend (by weight percent) were 70%, 50%, and 30%.

The BOY 50M Injection Molding machine was used to create the samples for tensile testing, falling dart impact testing, and void analysis testing. Processing conditions were held constant at the parameters displayed in Table 2 below, based on the properties recommended for processing the polyolefin used in the blend. The rear temperature was always held at or below 275ºF to prevent thermal degradation of the TPS while in the hopper.

Each 1-pound batch was sufficient material to clean the injection molding machine's barrel of old material and then create 2 warm-up samples before processing the 10 samples used for testing. After processing the 10 samples, one additional shot of resin was produced with the nozzle backed away from the sprue bushing. The resulting extrudate was then allowed to cool before being cross-sectioned to analyze for void formation. All samples were hermetically sealed after processing in order to prevent moisture absorption before testing.

Table 2: Injection Molding Conditions

Polymer		**Temperatures (ºF)**			**Injection Pressure (psi)**	
	Nozzle	Front	Mid	Rear	Front	Rear
HDPE	400	380	360	275	60	100
PP	420	410	392	275	30	30
ESR (non-blend)	360	340	300	250	60	100

3.3.3 Sample Testing

Three different tests were performed to examine the effects of the MC on the unblended TPS and on the TPS/polyolefin blends. The only non-mechanical test involved the use of a microscope to examine voids created by steam in the extrudate of each sample. Samples were obtained by cooling and then cross-sectioning extrudate for each batch. Cross section samples were then examined for voids as a percentage of the total cross sectional area through use of a Keyence VHX 500 digital microscope. To remain consistent, only voids visible at 50X magnification were measured. Each batch was sampled twice in different locations. The resulting value is the average of the two samples. Due to the near transparent nature of ESR, a red dye was used to enhance visibility of voids in cross section samples due to the fact that the surface would stain while voids remained unchanged.

In addition to examining the cross sections of extrudate, the second hypothesis was tested using a similar methodology with cross sections of injection-molded parts. Parts taken from each batch were randomly sampled from the tensile testing specimen population. To remain consistent, when examining finished parts, only voids visible at 50X magnification were measured.

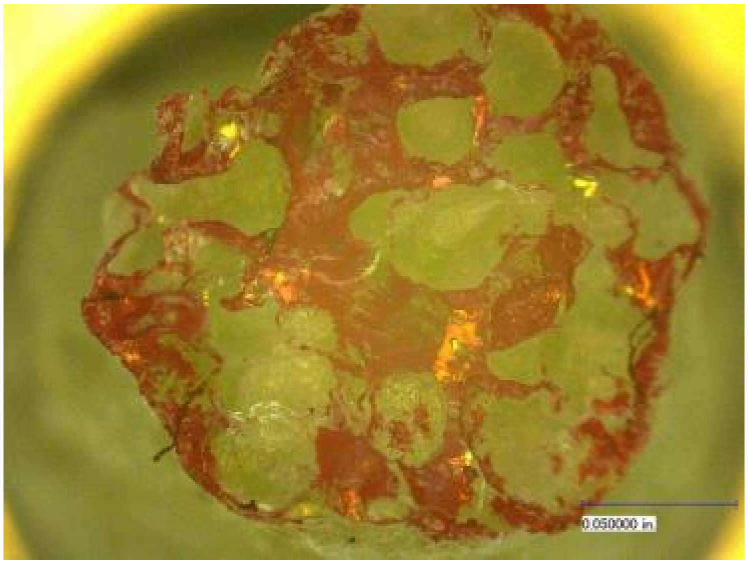


Figure 7: Example of Extrudate Cross Section with Voids (Dyed Red for Visibility)

Tensile testing was performed using a computer-controlled Instron 4204 machine. Samples were tested in accordance with the ASTM D 638-03 standards, using Type-I specimens. The machine was set to a nominal strain rate of 0.1 mm/mm · min, and to a 5 mm/min extension speed. Key measurements were Young's modulus and Tensile strength. Due to material constraints, only five specimens were tested for each blend/MC combination.

The second and final mechanical test was an impact test, using an Instron falling dart impact tester, as described by ASTM D5628 (ASTM International 2004). The test procedure involved dropping a weighted dart from a specified height onto the center of a thin plastic plate as it rested on a metal fixture. The machine is designed to drop the dart onto the plastic specimen with a hole positioned directly under the strike zone, in order to gather data regarding impact resistance. Parameters for this test include the use of a rounded tup, 0.52 inches in diameter, starting from a drop height consistent with a 2000 ft-lb drop energy potential. The data from this study was gathered as a comparison from one sample to another only—data is not intended to be referenced as an absolute measurement. Each tested batch consisted of a sample size of five.

3.4 **Data Analysis**

The effects of moisture content were studied by means of statistical analysis, with results reported from the two separate DOEs in addition to the results for the unblended TPS. A standard statistical software add-on for Microsoft Office Excel was used to perform multiple regression analysis for each of the dependent variables. All calculations were based on a 95% confidence level.

4 RESULTS

The multiple regression results for both DOEs are summarized in Table 3 below, showing which of the independent variables (percent moisture and polyolefin blend percent) were statistically significant for each dependent variable (modulus, tensile strength, impact energy, and percent voids), given the 95 percent confidence level.

Table 3: Results Showing Significance of Moisture % and Polyolefin Blend % for Two DOEs

DOE	Input	Young's Modulus	Tensile Strength	Impact Energy	Void%
HDPE	Moisture %	**0.00038***	0.06014	0.22135	**0.03443***
	Polymer Blend %	**0.00004***	**0.02985***	**0.00001***	0.79662
PP	Moisture %	0.83917	**0.00115***	0.36233	0.51720
	Polymer Blend %	**0.01799***	**0.00331***	**0.01814***	0.90172

*Statistically Significant at a 95% Confidence Interval

In addition to the two experiments summarized above, an identical experiment was performed on the unblended TPS (summarized in Table 4 below).

Table 4: Results Showing Significance of Moisture % for Unblended TPS

DOE	Input	Young's Modulus	Tensile Strength	Impact Energy	Void%
ESR	Moisture %	**0.00149***	0.86492	0.11541	**0.00255***

*Statistically Significant at a 95% Confidence Interval

4.1 **Void Formation**

As discussed above, the process for analyzing the effect of TPS moisture on void formation involved the use of multiple regression analysis, where the two independent variables were percent moisture and polyolefin blend percent and the dependent variable was percent voids.

4.1.1 HDPE Blends and Void Formation

As stated in the first and second hypotheses, one of the major purposes of this study was to examine the effect of moisture on void formation in both melt from the nozzle as well as in finished injection-molded parts.

An examination of cross sections of melt taken from the machine nozzle revealed that the effect of MC on the formation of voids in TPS blended with HDPE was statistically significant. This effect was also visibly evident, as illustrated by the pictures in Figure 8. More specifically, the change from 0.57 percent to 1.37 percent moisture caused the percentage of voids to increase by 350 percent at blend ratios of 30% HDPE or to increase by 310 percent at blend ratios of 70% HDPE, as illustrated in Table 5.

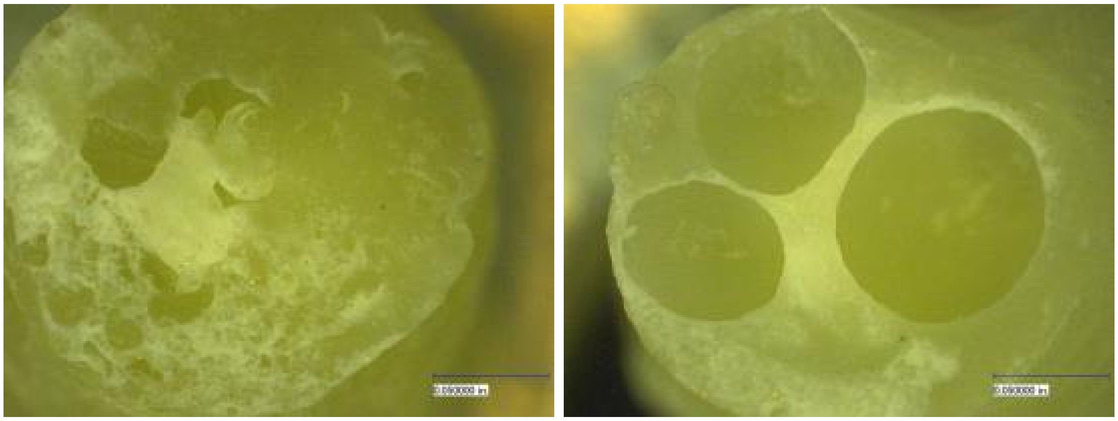


Figure 8: Void % of HDPE Blends Were Affected by MC; 0.59% MC (left); 1.37% MC (right)

Table 5: Percent Change in Void % in Melt Cross Sections from Minimum Moisture to Maximum Moisture

HDPE Blend	Void % @ Min MC (0.59%)	Void % @ Max MC (1.37%)	% Change
30%	8.64	38.56	346%
70%	10.75	43.99	309%

Despite the conclusion that MC was related to void formation, there was no effect of MC on void formation in the injection-molded parts of TPS/HDPE blends. In fact, no voids were detected in the TPS/HDPE parts—likely due to effective venting in the mold (Figure 9). Due to the fact that no voids were detected in injection-molded parts, this study fails to reject the hypothesis that voids within the melt of the injection mold machine have an effect on the creation of voids within the injection-molded parts. Likewise, no relationship can be inferred between voids within the finished part and mechanical performance of TPS/HDPE parts.

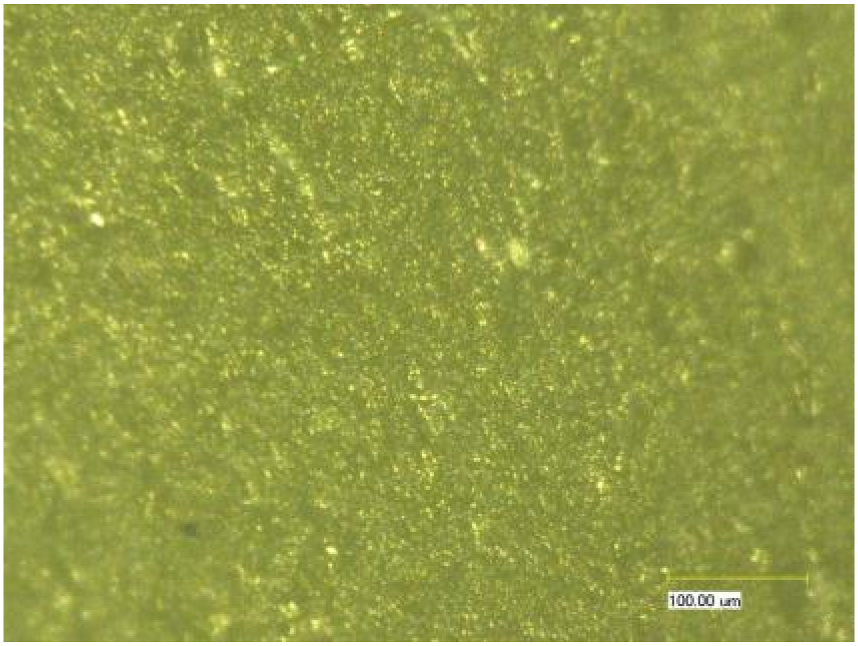


Figure 9: Cross Section of Injection-molded TPS/HDPE Part with Zero Voids

4.1.2 PP Blends and Void Formation

The effect of MC on the formation of voids in TPS blended with PP was not statistically significant. At 50x magnification (or at any greater magnification), it was difficult to perceive any physical difference in size or number of voids as affected by different blend and moisture levels.

One interesting observation was made regarding the presence of large TPS granules visible in the PP blends (visible as amber-colored spots in the figure above). This lack of homogenous compounding of the TPS and PP occurred at all blend and MC levels. A multiple regression was taken based on percentage area of TPS granules in melt cross sections (using the same methodology as the percent void measurement), however neither moisture nor blend percent significantly affected the percent TPS area in cross sections.

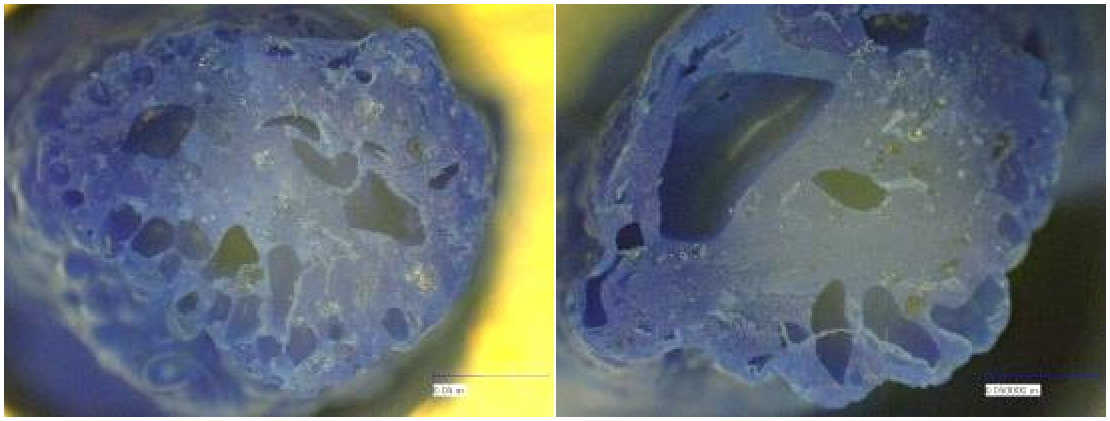


Figure 10: No Significant Effect of MC on Void % of PP Blends; 0.57% MC (left) with 17% Voids; 1.44% MC (right) with 15% Voids

Similar to the HDPE blend samples, the hypothesis of void formation in injection-molded parts was tested. In this case, voids were detected in injection-molded samples under a microscope at 500x magnification (Figure 11). However, there was no real correlation established between void percent of melt cross sections and void percent within injection-molded parts. The observation was made that the majority of voids detected in the cross sections of injection-molded parts were visible only in the TPS granules found in sample cross sections. This raises the possibility that voids within starch granules could act as a defect in TPS/PP blended samples.

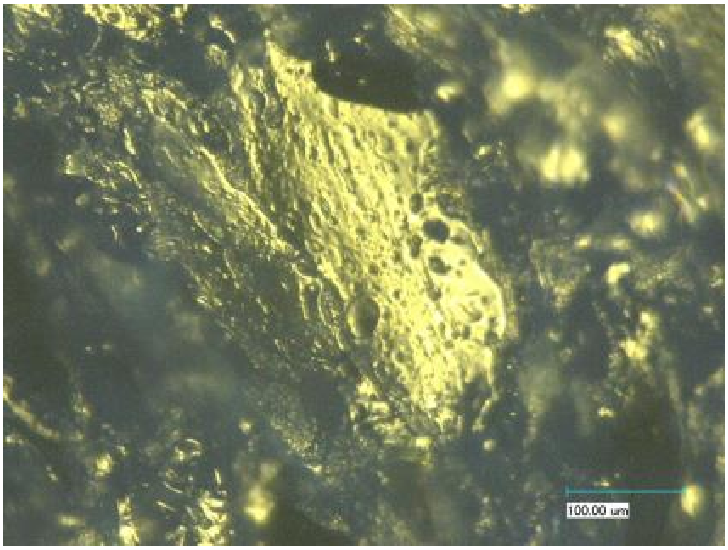


Figure 11: Cross Section of Injection-molded TPS/PP Part. Note the Voids Prevalent in the Amber-colored ESR

4.1.3 Void Formation in Unblended TPS

The effect of MC on the formation of voids in unblended TPS was statistically significant and visibly evident, similar to the HDPE blends (Figure 12). Increasing moisture from 0.59% to 1.37% had the effect of increasing voids in unblended TPS by nearly 150% (see Table 6).

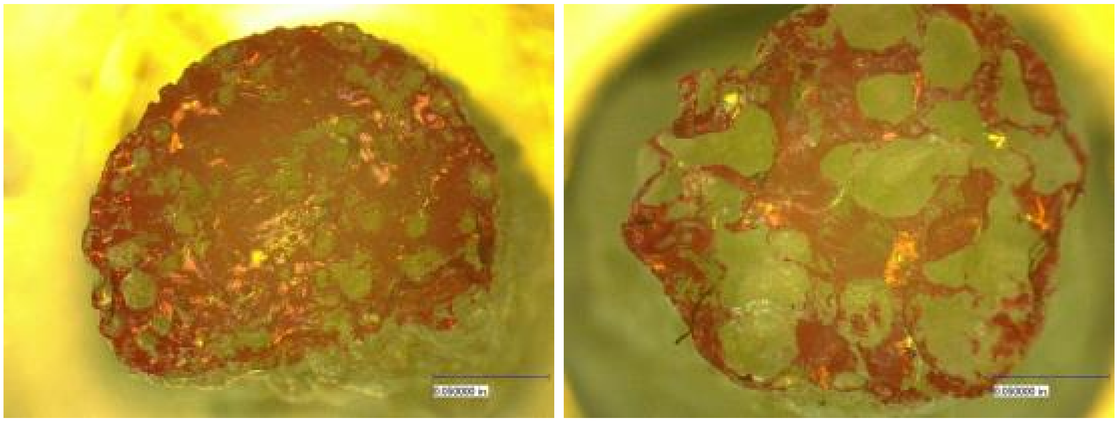


Figure 12: Void % of TPS Was Affected by MC. 0.59% MC (left) and 1.37% MC (right)

Table 6: Percentage Decrease in Voids as Moisture Changes from Minimum to Maximum

Void % @ Min MC (0.43%)	Void % @ Max MC (1.44%)	% Change
16.75%	41.66%	149%

Voids were detected in injection-molded samples of the unblended TPS (Figure 13). However, there was no significant correlation between void percent of melt cross sections and void percent in injection-molded parts.

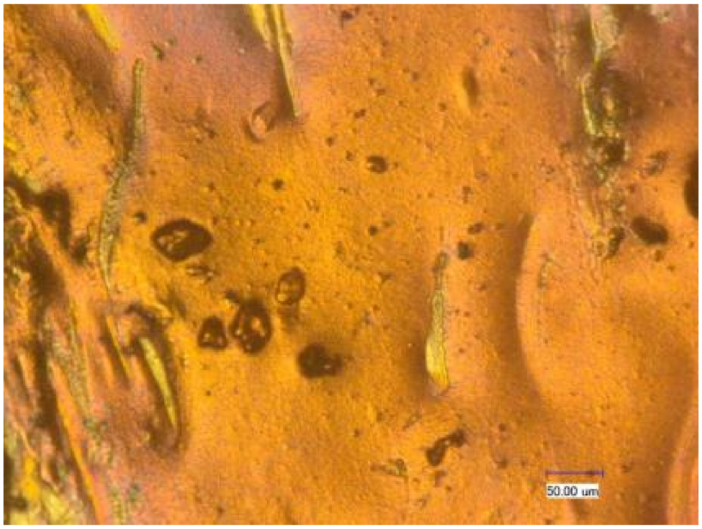


Figure 13: Cross Section of Injection-molded TPS Part (Unblended).

4.2 Tensile Properties

As discussed above, the process for analyzing the effect of TPS moisture on tensile properties involved the use of multiple regression, where the two independent variables were percent moisture and polyolefin blend percent and the dependent variables were Young's modulus and Tensile Strength.

The apparent effect of polyolefin blend percent on tensile properties was expected. Referring to Figure 14 and Figure 15 below, as the TPS/polyolefin ratio decreases, the blended sample begins to act more like the polyolefin and less like the TPS.

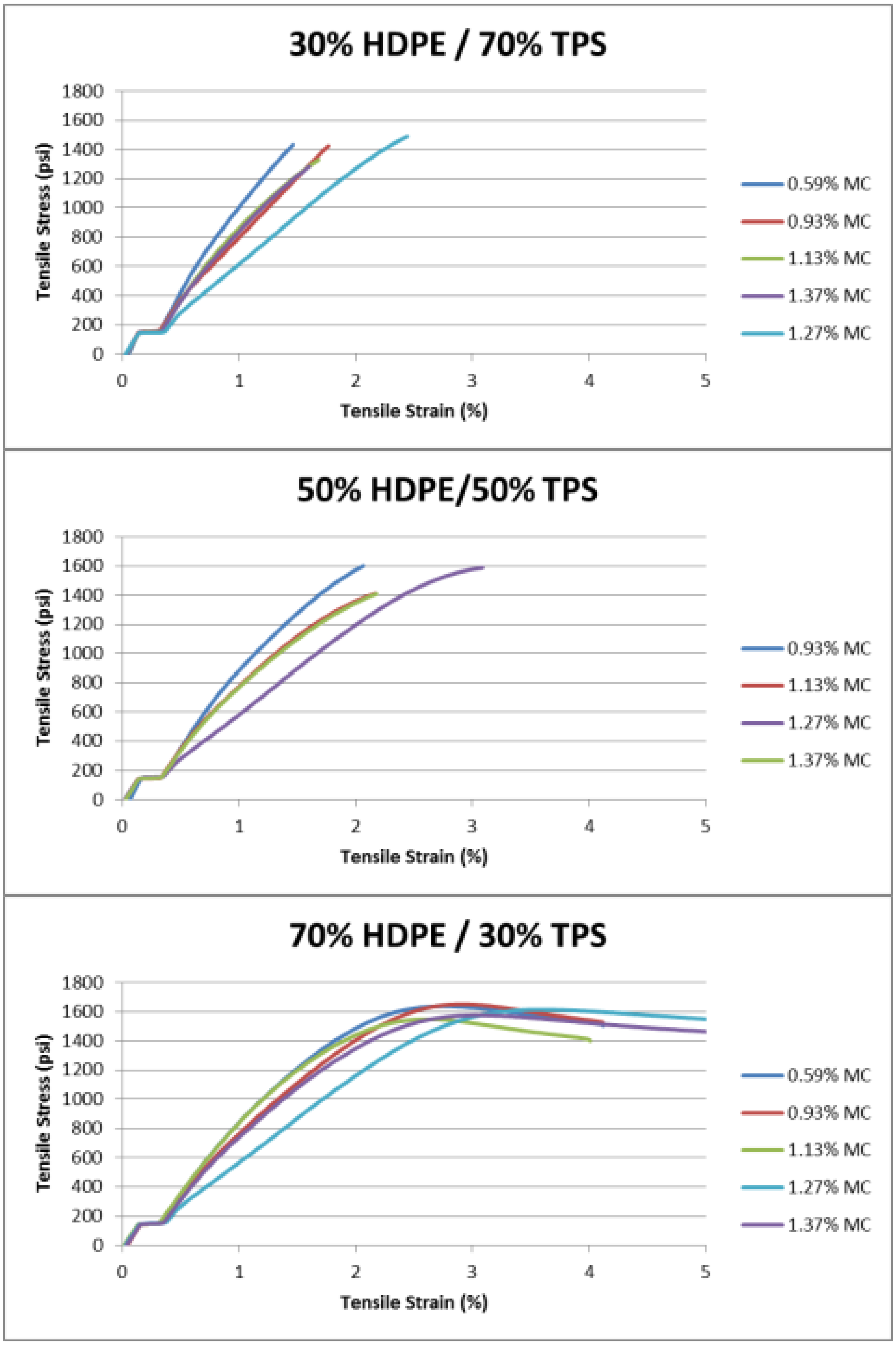
4.2.1 HDPE Blends and Tensile Properties

Both moisture percent and polyolefin blend percent had a significant effect on the tensile properties for TPS/HDPE blends. Specifically, a rise in MC from 0.59 percent to 1.37 percent caused the Young's modulus to decrease by 14 percent at blend ratios of 30% HDPE or decrease by 9 percent at blend ratios of 70% HDPE, as illustrated in Table 7. As the MC of the sample increased, the modulus generally decreased, indicating a softening effect. Samples with the least amount of moisture generally had greater stiffness. This confirms the general behavior of starch, where water acts as a plasticizer. The samples could be likened to a spaghetti noodle—when moisture is added, the noodle loses its stiffness (lower modulus).

Table 7: Percent Change in Modulus in TPS/HDPE Blends from Minimum Moisture to Maximum Moisture

HDPE Blend	Modulus @ Min MC (0.59%)	Modulus @ Max MC (1.37%)	% Change
30%	176198	150701	14%
70%	136865	125055	9%

The MC of the samples did not have a significant effect on tensile strength for the HDPE/TPS blend, as illustrated in Figure 14. However, the polyolefin blend percent did have a significant effect on both modulus and on the tensile strength of samples tested.


30% HDPE / 70% TPS

50% HDPE/50% TPS

70% HDPE / 30% TPS

Figure 14: MC Did Not Have a Significant Effect on Tensile Strength

4.2.2 PP Blends and Tensile Properties

The MC of the samples did not have a significant effect on the Young's modulus of PP/TPS blends. However, MC did significantly affect the tensile strength of samples. An increase in MC was generally correlated with an increase in tensile strength of the samples tested. More specifically, by raising MC from 0.57 percent to 1.44 percent, the tensile strength of samples increased by 34 percent at a blend ratio of 30% PP and increased by 22 percent at a blend ratio of 70% PP (Table 8).

Table 8: Percent Change in Tensile Strength of TPS/PP Blends from Minimum Moisture to Maximum Moisture

PP Blend	Tensile Strength @ Min MC (0.57%)	Tensile Strength @ Min MC (1.44%)	% Change
30%	760	1022	34%
70%	1005	1231	22%

Similar to the HDPE/TPS blends, the polyolefin blend percent had a significant influence on both the modulus and the tensile strength of samples tested (Figure 15).

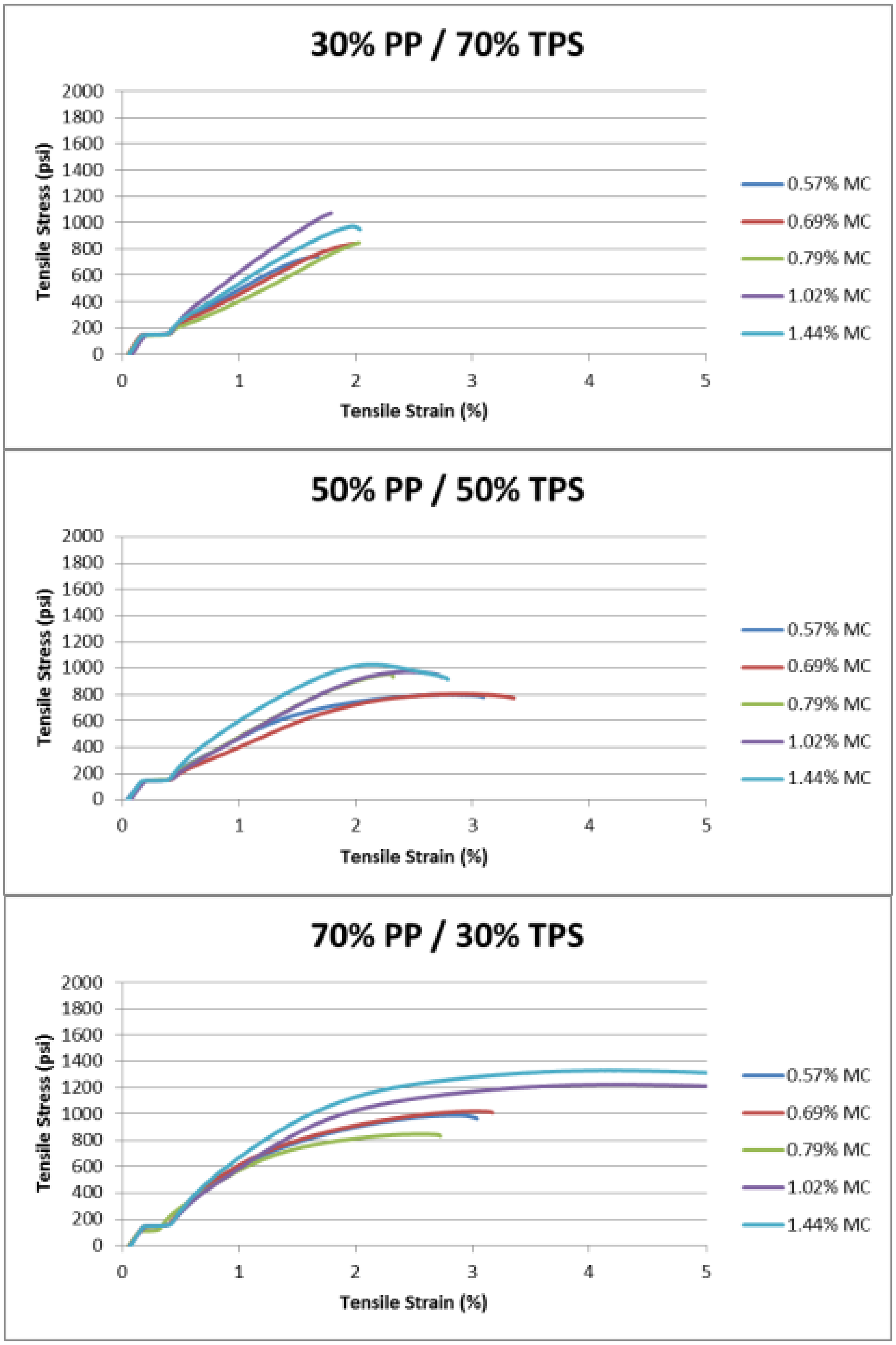


Figure 15: Increasing the Moisture Generally Increases the Tensile Strength in TPS/PP Blends. Note that Increasing PP Levels Also Had an Effect on Increasing Tensile Strength

4.2.3 Unblended TPS and Tensile Properties

Moisture percent had a significant effect on the tensile properties for unblended TPS, similar to the result for TPS/HDPE blend. Increasing moisture percent had the effect of slightly lowering the modulus. More specifically, when moisture levels increased from 0.43 percent moisture to 1.44 percent moisture, the modulus decreased by 25% (Table 9). However, there was no significant correlation between the TPS moisture and its tensile strength (Figure 16).

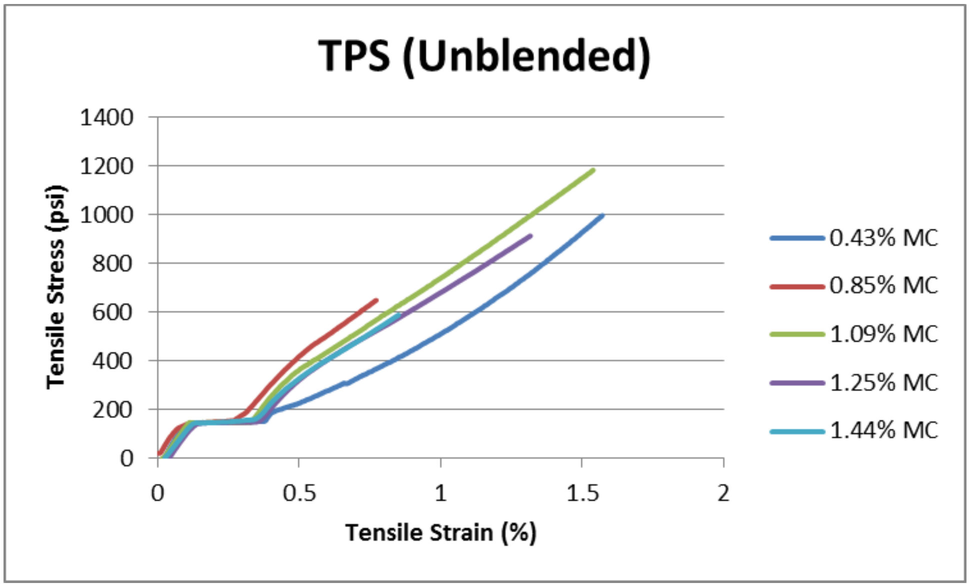


Figure 16: Moisture Did Not Affect the Tensile Strength of TPS Samples.

Table 9: Percentage Decrease in Modulus of Unblended TPS as Moisture Increases from Minimum to Maximum

Modulus @ Min MC (0.43%)	Modulus @ Max MC (1.44%)	% Change
198404	149483	25%

4.3 **Impact Properties**

Similar to void formation and tensile testing, the process for analyzing the effect of TPS moisture on impact properties involved the use of a multiple regression analysis, where the two independent variables were percent moisture and polyolefin blend percent and the dependent variable was impact energy.

There was no positive correlation detected between MC and impact energy. However, for both polyolefin blends (HDPE and PP) the blend percent had a significant effect on impact energy. This relationship is expected, since the test specimens should absorb different amounts of energy based on their polyolefin composition (Figure 17).

Similar to the blended TPS, the unblended TPS samples showed that MC had no effect on impact energy, with only a one percent decrease in impact energy as moisture was increased from 0.43% MC to 1.44% MC (Figure 18).

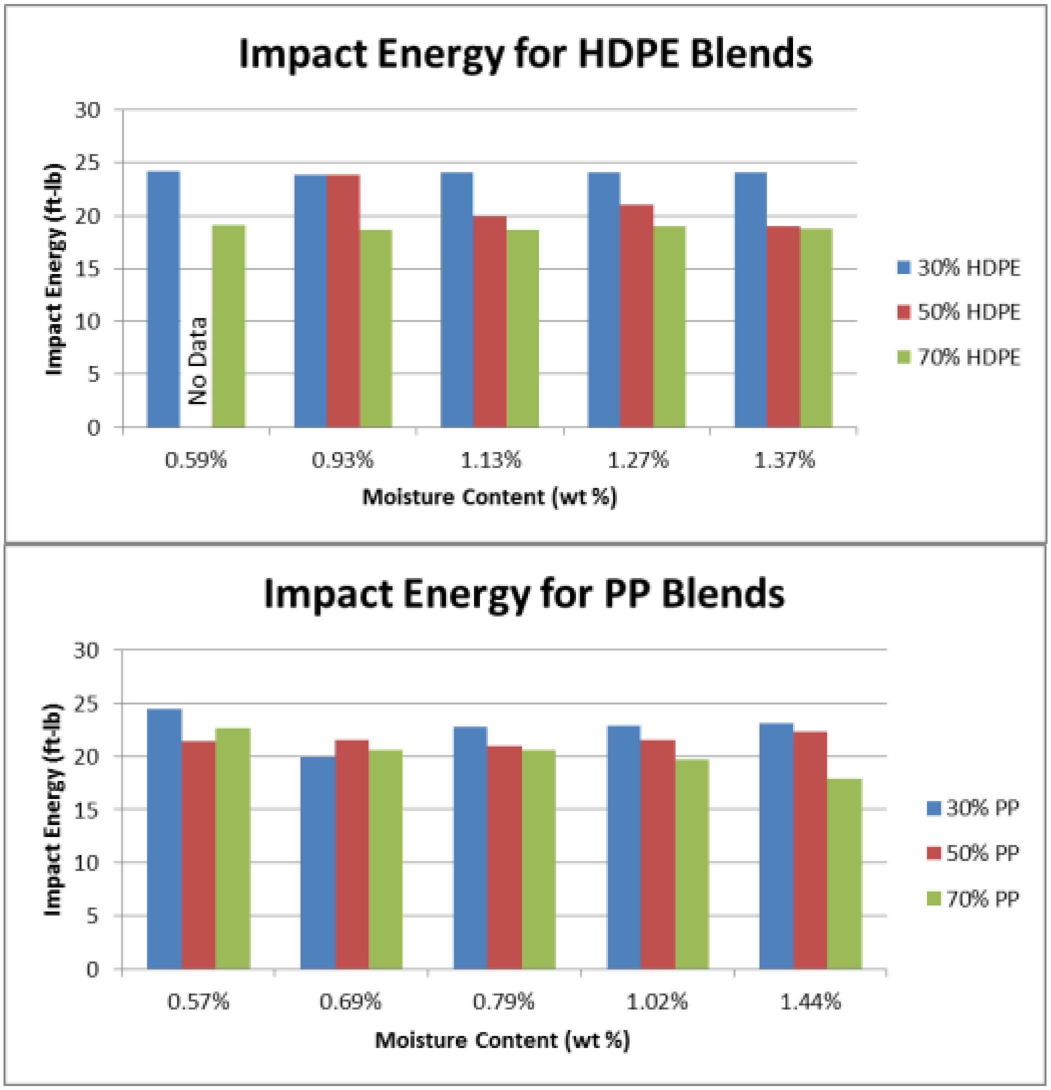


Figure 17: The Only Effect on Impact Energy for TPS/polyolefin Blends Was the Polyolefin Blend %

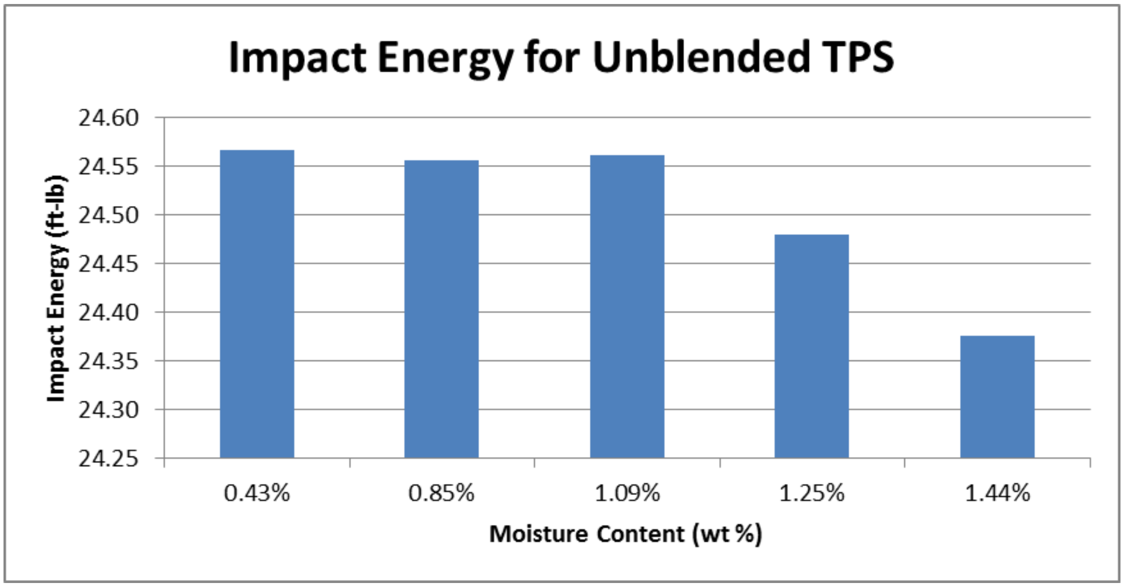


Figure 18: Moisture Content Did Not Have Significant Effect on Impact Energy of Unblended TPS

4.4 Relationship between Voids and Mechanical Performance of Injection-molded Part

To further test the effects of MC on TPS, the data sets taken from the above-mentioned tests were used to examine whether voids had an effect on mechanical performance. Once again, these relationships were determined through statistical regression analysis as summarized in Table 10.

Table 10: The Effects of Voids (in Melt and in Finished Parts) on Mechanical Performance in TPS/Polyolefin Blends. This Table Also Shows that ESR Granules in TPS/PP Blends Had an Effect on Tensile Strength

DOE	Input	Young's Modulus	Tensile Strength	Impact Energy
HDPE	Void %	0.353916	0.08566	0.658241
	Part Void %	N/A	N/A	N/A
PP	Void %	0.79658	0.095305	0.902179
	Part Void %	0.832095	0.780433	0.736898
	ESR %	0.230337	**0.04100***	0.800818

*Statistically Significant at a 95% Confidence Interval

TPS/HDPE blends: When examining cross sections of melt for TPS/HDPE blends it was determined that the percentage of voids in the melt had no effect on any mechanical performance measure from this study. Furthermore, no voids were found in cross sections of injection-molded parts (Figure 9).

TPS/PP blends: Cross sections of melt for TPS/PP blends held a similar result—there was no significant relationship between void percent in the cross sections of melt and the mechanical performance of injection-molded TPS/PP parts. Also, as stated above, there was no evidence that the void percent of melt cross sections had any effect on the void percent within injection-molded parts. Similarly, the void percent in finished TPS/PP parts had no significant effect any of the mechanical properties tested.

One interesting observation was made regarding the TPS granules visible in the TPS/PP blend. A regression analysis revealed that the percentage of ESR granules area in the cross section of melt had an effect on the finished part's tensile strength (though there was no effect on Young's modulus or on impact energy). However, given the above-stated observation (that voids in finished parts have no effect on mechanical properties), it cannot be concluded that the voids localized within the ESR granules of TPS/PP parts affect tensile properties of these parts.

Unblended TPS: Unlike the polyolefin blends, the voids in the melt of unblended TPS had a significant effect on Young's Modulus of tensile testing samples. However, the void percent of finished TPS parts had no significant effect on any tensile properties tested.

Table 11: The Effects of Voids (in Melt and in Finished Parts) on Mechanical Performance in Unblended TPS

DOE	Input	Young's Modulus	Tensile Strength	Impact Energy
ESR	Void %	**0.00682***	0.75759	0.208947
	Part Void %	0.525446	0.86969	0.938023

*Statistically Significant at a 95% Confidence Interval

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Through a series of experiments, this study identified the relationship between TPS moisture content and void creation in the melt of injection molded parts—both as a stand-alone resin as well as a blend with HDPE and with PP. TPS moisture appeared to have a significant effect on void percent in the cross section of melt for TPS/HDPE blends and for TPS alone (with no significant effect on void percent in PP). Additionally, the possible relationship between percent voids in the melt and percent voids in the injection-molded part was explored. Though voids were detected in the final parts of TPS/PP blends and unblended TPS, there was no statistical correlation found between the measurements for voids in the final part and the measured mechanical performance.

The designed experiments also explored the relationship between TPS moisture content and mechanical performance as measured by tensile and impact testing. A negative correlation was found between MC and Young's modulus values for both the TPS/HDPE blend and the unblended TPS. Also, the TPS/PP blend showed a positive correlation between MC and tensile strength. The polyolefin blend percent significantly affected all mechanical test results.

5.2 Conclusions

In order to determine the effect of moisture on void formation in in TPS, the following hypotheses were tested:

Hypothesis 1: *The level of moisture content of the TPS resin has an effect on the size and number of voids in the melt of an injection-molded part.* This hypothesis was not rejected for TPS/HDPE blends or for unblended TPS. The hypothesis was rejected for TPS/PP blends.

Hypothesis 2: *Voids within the injection-molded part are directly related to the amount of voids in the melt.* This hypothesis was rejected for TPS/PP blends as well as for unblended TPS. It was not rejected for TPS/HDPE blends due to fact that zero voids were detected in finished parts of this blend.

Hypothesis 3: *The level of moisture content of the TPS resin has an effect on the tensile and impact performance of injection-molded samples.* This hypothesis was not rejected for tensile testing, since the TPS/HDPE blend and the unblended TPS both had modulus values that were significantly affected by the TPS moisture. Also, PP/HDPE blends showed a positive correlation between MC and tensile strength. This hypothesis was rejected for impact testing, however, since moisture had no significant effect on impact performance of TPS (both blended and unblended).

5.3 Discussion

5.3.1 Relationship between MC, Voids, and Performance

As stated in the previous chapter, there was no statistical correlation established between void percent in injection-molded parts and the mechanical performance values measured in this study. Similarly, there was no significant correlation between percent voids in the extrudate cross sections and mechanical performance of injection-molded parts when blended with HDPE or with PP. It is concluded, therefore, that the relationships identified between MC and voids and between MC and mechanical performance cannot be directly connected. In other words, had this study hypothesized that voids within the melt of the injection mold machine *that were caused by MC*, would affect mechanical performance, then this study would fail to reject the hypothesis for TPS/polyolefin blends.

In the case of unblended TPS, this study first established a positive correlation between MC and percent voids found in the cross section of extrudate. It was later established that the percent voids in extrudate had an effect on the modulus of TPS samples. It is concluded, therefore, that had this study hypothesized that voids within the melt of the injection mold machine *that were caused by MC*, would affect mechanical performance, then this study would fail to reject the hypothesis for TPS/polyolefin blends.

5.3.2 Problems in Blending PP and TPS

As previously observed, the PP and TPS did not fully compound during injection molding processing. The cause of this phenomenon is unknown. However, there was speculation that this incomplete blending may have been a result of thermal degradation of the starch due to the relatively high processing temperatures necessary for processing PP compared to the processing temperatures used for the ESR resin. Another possible explanation might relate to the small size and screw configuration of the BOY 55 injection molding machine involved—especially given its relatively short screw and only three heating zones. Potential questions for further study could address the possibility of there being incompatibility between PP and ESR pellets.

5.3.3 Differences in Findings

As discussed above, one unexpected result was the fact that for TPS/HDPE blends, MC had a significant effect on modulus but not tensile strength, while TPS/PP blends did not have a significant effect on modulus, but did have a significant effect on modulus. One possible explanation for this could relate to the earlier observation regarding incomplete compounding of TPS/PP blends. The lack of significant effect of MC in TPS/PP blends could be attributed to the fact that moisture from the TPS did not leave the TPS, as evidenced by the voids found in ESR granules within the TPS/PP blends. Similarly, the fact that MC did have an effect on the tensile strength of TPS/PP blends (contrary to the TPS/HDPE blends) could relate to the incomplete compounding of TPS/PP blends. The large, hard, granules of ESR within TPS/PP samples may have acted as defects while tensile testing.

5.4 **Recommendations**

These experiments showed that there is a relationship between TPS moisture and its physical properties in injection-molded applications. In hindsight, however, there were certain limitations to the research which, if addressed, could be beneficial to future research in this area.

The first problem related to the mold used to create samples. The alignment of the mold's sprue and the sprue bushing was slightly off-center due to years of wear. This defect created significant delays in cycle times due to the frequent necessity of manual removal of injection-molded parts. The cycle time variation could have introduced deviations in moisture content, thermal degradation, and cooling that could affect results. Therefore, the first recommendation is to use a different (or repaired) mold that would enable speedy processing with little variation.

The second problem related to the incomplete compounding of the TPS with the PP. The samples used in this study should be replaced by samples that are homogeneously compounded. Therefore, the second recommendation is to use a twin-screw injection mold machine with longer or more heating zones to ensure complete compounding. A homogenous mixture of TPS/PP will enable a more-accurate study of the effects of voids within injection-molded parts on their mechanical performance.

A third problem relates to the narrow scope of this study. This research was limited to two polyolefin blends due in part to material availability at the time of the study. However, HDPE is a wise choice for a TPS blend due to its potential application in creating compostable bags or containers. PP can be used in similar applications. However, the third recommendation is to expand this study to other common thermoplastics such as polycarbonate, polystyrene, or polyvinylchloride.

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APPENDICES

APPENDIX A: EXPERIMENTAL DESIGNS AND DATA

DOE for PP Blends, Including Mean Results for Each Run

Blend: PP

Run	Factors		Result			
	Moisture %	Polymer Blend %	Young's Modulus (psi)	Tensile Strength (psi)	Impact Energy (ft-lb)	Void Area (%)
1	1	1	151,699	760	24.41	11.53
2	1	2	124,022	807	21.41	8.99
3	1	3	115,511	1,005	22.60	16.81
4	2	1	145,055	856	19.97	13.01
5	2	2	118,293	818	21.56	6.80
6	2	3	112,768	1,104	20.57	21.58
7	3	1	137,076	889	22.74	24.23
8	3	2	127,707	962	20.97	11.20
9	3	3	119,598	1,050	20.66	11.51
10	4	1	137,944	1,097	22.82	20.65
11	4	2	123,388	1,004	21.47	9.49
12	4	3	114,695	1,108	19.75	29.37
13	5	1	137,519	1,022	23.11	22.11
14	5	2	128,566	1,037	22.26	9.35
15	5	3	113,615	1,231	17.87	15.07

Key: PP

Level	Moisture %	TPS Blend %
1	0.57%	30%
2	0.69%	50%
3	0.79%	70%
4	1.02%	-
5	1.44%	-

DOE for HDPE Blends, Including Mean Results for Each Run

Blend: HDPE

Run	Factors		Result			
	Moisture %	Polymer Blend %	Young's Modulus (psi)	Tensile Strength (psi)	Impact Energy (ft-lb)	Void Area (%)
1	1	1	176,198	1,555	24.23	8.64
2*	1	2	*No results gathered due to processing problems			
3	1	3	136,865	1,644	19.06	10.75
4	2	1	164,196	1,546	23.82	14.68
5	2	2	153,392	1,668	23.89	16.96
6	2	3	130,900	1,656	18.64	17.87
7	3	1	149,349	1,416	24.06	26.41
8	3	2	137,491	1,445	19.86	27.62
9	3	3	128,868	1,524	18.70	27.77
10	4	1	136,503	1,558	24.06	11.67
11	4	2	129,435	1,598	20.99	27.82
12	4	3	123,097	1,617	19.01	7.67
13	5	1	150,701	1,367	24.10	38.56
14	5	2	132,422	1,443	18.96	19.83
15	5	3	125,055	1,578	18.78	43.99

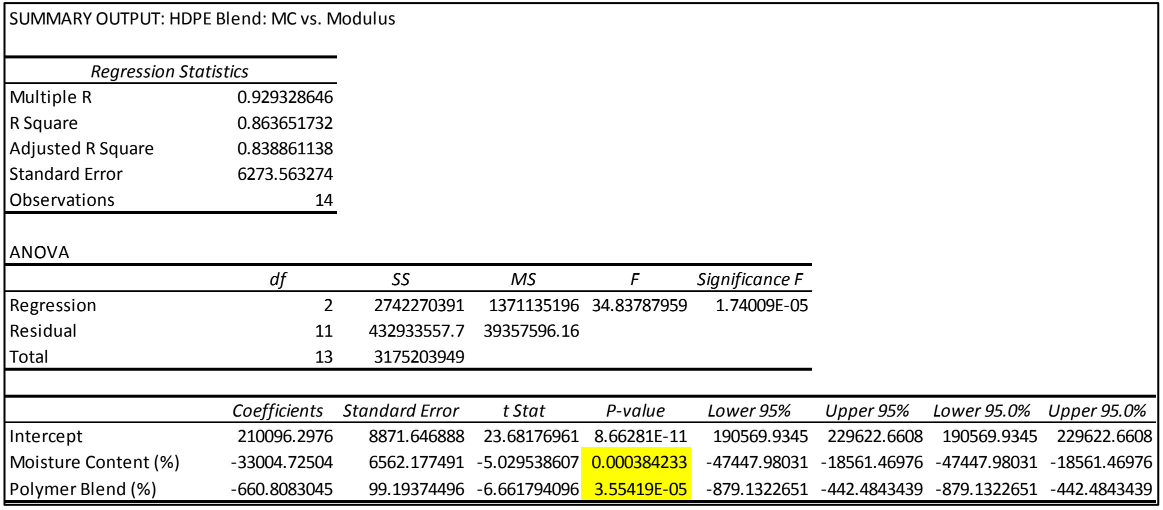
Key: HDPE

Level	Moisture %	TPS Blend %
1	0.59%	30%
2	0.93%	50%
3	1.13%	70%
4	1.27%	-
5	1.37%	-

APPENDIX B: REGRESSION RESULTS

Dependent Variable: Young’s Modulus

HDPE Blend: MC and Blend% vs. Young’s Modulus



SUMMARY OUTPUT: HDPE Blend: MC vs. Modulus

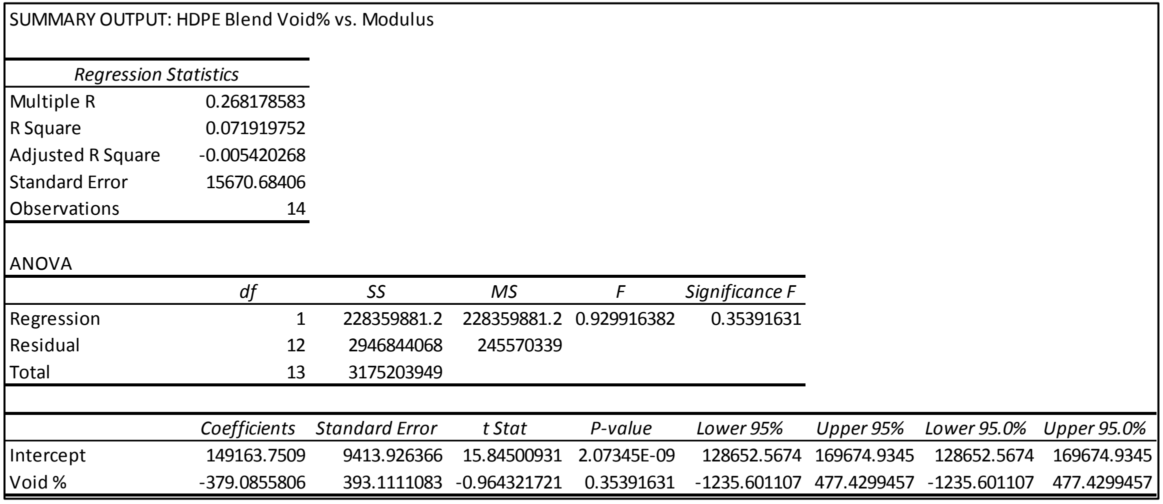
Regression Statistics	
Multiple R	0.929328646
R Square	0.863651732
Adjusted R Square	0.838861138
Standard Error	6273.563274
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	2742270391	1371135196	34.83787959	1.74009E-05
Residual	11	432933557.7	39357596.16		
Total	13	3175203949			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	210096.2976	8871.646888	23.68176961	8.66281E-11	190569.9345	229622.6608	190569.9345	229622.6608
Moisture Content (%)	-33004.72504	6562.177491	-5.029538607	0.000384233	-47447.98031	-18561.46976	-47447.98031	-18561.46976
Polymer Blend (%)	-660.8083045	99.19374496	-6.661794096	3.55419E-05	-879.1322651	-442.4843439	-879.1322651	-442.4843439

HDPE Blend: Void% vs. Young's Modulus



SUMMARY OUTPUT: HDPE Blend Void% vs. Modulus

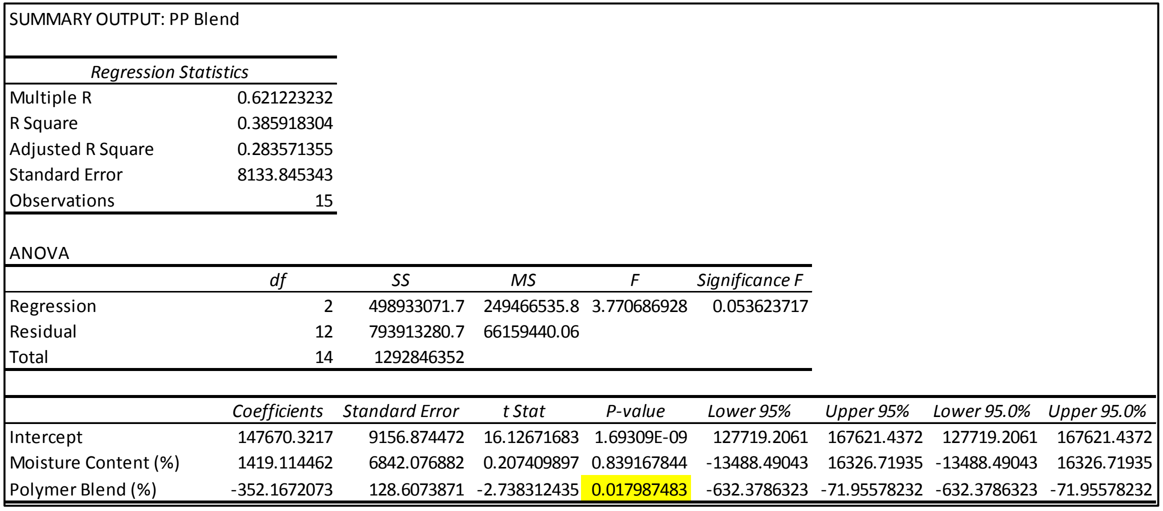
Regression Statistics	
Multiple R	0.268178583
R Square	0.071919752
Adjusted R Square	-0.005420268
Standard Error	15670.68406
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	228359881.2	228359881.2	0.929916382	0.35391631
Residual	12	2946844068	245570339		
Total	13	3175203949			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	149163.7509	9413.926366	15.84500931	2.07345E-09	128652.5674	169674.9345	128652.5674	169674.9345
Void %	-379.0855806	393.1111083	-0.964321721	0.35391631	-1235.601107	477.4299457	-1235.601107	477.4299457

PP Blend: MC and Blend% vs. Young's Modulus



SUMMARY OUTPUT: PP Blend

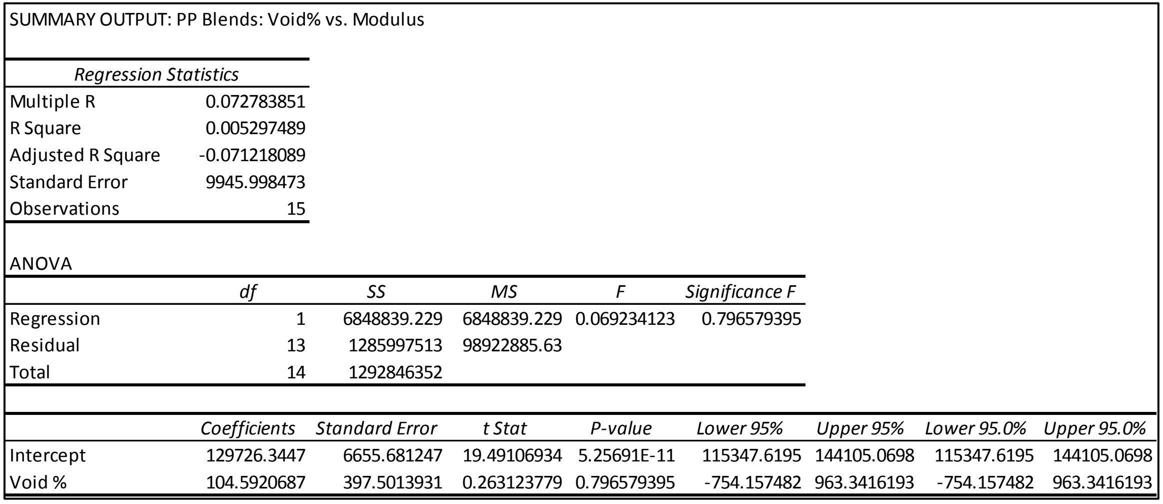
Regression Statistics	
Multiple R	0.621223232
R Square	0.385918304
Adjusted R Square	0.283571355
Standard Error	8133.845343
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	498933071.7	249466535.8	3.770686928	0.053623717
Residual	12	793913280.7	66159440.06		
Total	14	1292846352			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	147670.3217	9156.874472	16.12671683	1.69309E-09	127719.2061	167621.4372	127719.2061	167621.4372
Moisture Content (%)	1419.114462	6842.076882	0.207409897	0.839167844	-13488.49043	16326.71935	-13488.49043	16326.71935
Polymer Blend (%)	-352.1672073	128.6073871	-2.738312435	0.017987483	-632.3786323	-71.95578232	-632.3786323	-71.95578232

PP Blend: Void% vs. Young's Modulus



SUMMARY OUTPUT: PP Blends: Void% vs. Modulus

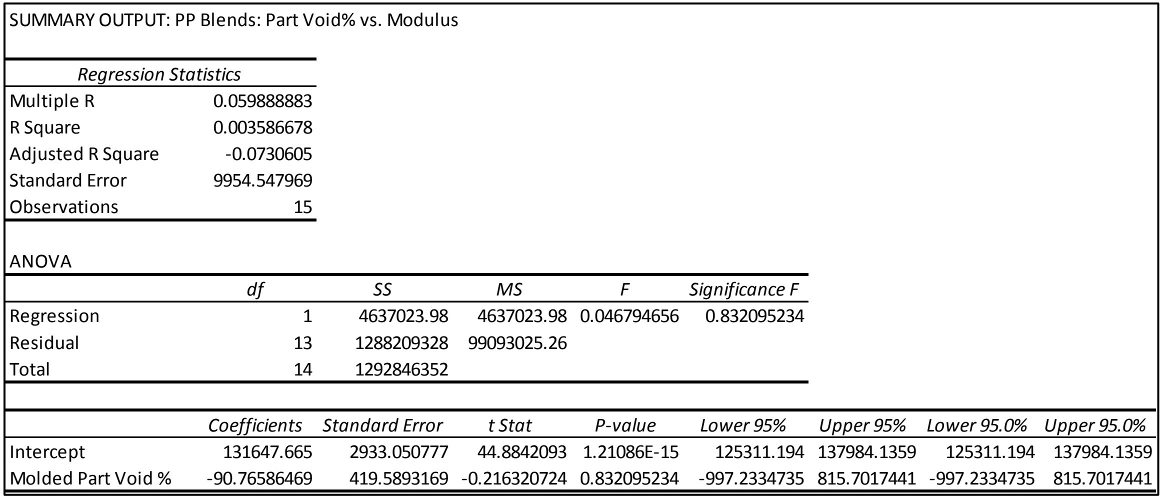
Regression Statistics	
Multiple R	0.072783851
R Square	0.005297489
Adjusted R Square	-0.071218089
Standard Error	9945.998473
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6848839.229	6848839.229	0.069234123	0.796579395
Residual	13	1285997513	98922885.63		
Total	14	1292846352			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	129726.3447	6655.681247	19.49106934	5.25691E-11	115347.6195	144105.0698	115347.6195	144105.0698
Void %	104.5920687	397.5013931	0.263123779	0.796579395	-754.157482	963.3416193	-754.157482	963.3416193

PP Blend: Injection-molded Part Void% vs. Young's Modulus



SUMMARY OUTPUT: PP Blends: Part Void% vs. Modulus

Regression Statistics	
Multiple R	0.059888883
R Square	0.003586678
Adjusted R Square	-0.0730605
Standard Error	9954.547969
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4637023.98	4637023.98	0.046794656	0.832095234
Residual	13	1288209328	99093025.26		
Total	14	1292846352			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	131647.665	2933.050777	44.8842093	1.21086E-15	125311.194	137984.1359	125311.194	137984.1359
Molded Part Void %	-90.76586469	419.5893169	-0.216320724	0.832095234	-997.2334735	815.7017441	-997.2334735	815.7017441

PP Blend: ESR% in Melt Cross Section vs. Young's Modulus

SUMMARY OUTPUT: PP Blend: ESR% vs. Modulus

Regression Statistics	
Multiple R	0.329551677
R Square	0.108604308
Adjusted R Square	0.040035409
Standard Error	9415.362523
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	140408683.5	140408683.5	1.583871246	0.230336852
Residual	13	1152437669	88649051.45		
Total	14	1292846352			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	135622.5411	4180.721717	32.43998292	7.95901E-14	126590.6409	144654.4413	126590.6409	144654.4413
ESR%	-373.8984967	297.0939321	-1.258519466	0.230336852	-1015.730916	267.9339222	-1015.730916	267.9339222

Unblended ESR: MC vs. Young's Modulus

SUMMARY OUTPUT: ESR

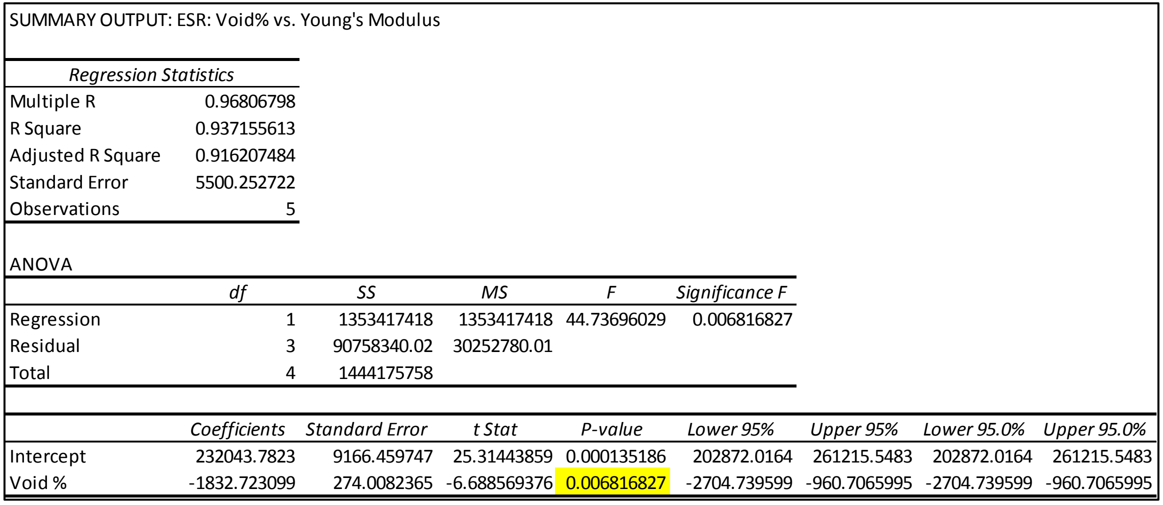
Regression Statistics	
Multiple R	0.988411654
R Square	0.976957597
Adjusted R Square	0.969276796
Standard Error	3330.529479
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1410898478	1410898478	127.1947544	0.001494892
Residual	3	33277279.83	11092426.61		
Total	4	1444175758			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	221617.1701	4562.346475	48.57526085	1.92116E-05	207097.7474	236136.5928	207097.7474	236136.5928
Moisture Content (%)	-48058.46875	4261.233461	-11.27806519	0.001494892	-61619.61544	-34497.32207	-61619.61544	-34497.32207

Unblended ESR: Void % vs. Young's Modulus



SUMMARY OUTPUT: ESR: Void% vs. Young's Modulus

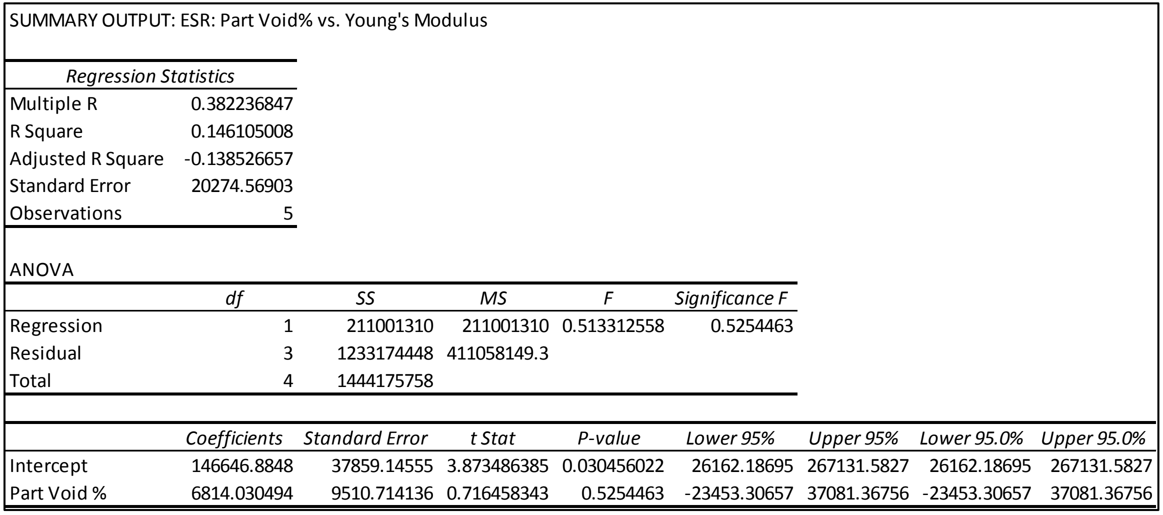
Regression Statistics	
Multiple R	0.96806798
R Square	0.937155613
Adjusted R Square	0.916207484
Standard Error	5500.252722
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1353417418	1353417418	44.73696029	0.006816827
Residual	3	90758340.02	30252780.01		
Total	4	1444175758			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	232043.7823	9166.459747	25.31443859	0.000135186	202872.0164	261215.5483	202872.0164	261215.5483
Void %	-1832.723099	274.0082365	-6.688569376	0.006816827	-2704.739599	-960.7065995	-2704.739599	-960.7065995

Unblended ESR: Injection-molded Part Void% vs. Young's Modulus



SUMMARY OUTPUT: ESR: Part Void% vs. Young's Modulus

Regression Statistics	
Multiple R	0.382236847
R Square	0.146105008
Adjusted R Square	-0.138526657
Standard Error	20274.56903
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	211001310	211001310	0.513312558	0.5254463
Residual	3	1233174448	411058149.3		
Total	4	1444175758			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	146646.8848	37859.14555	3.873486385	0.030456022	26162.18695	267131.5827	26162.18695	267131.5827
Part Void %	6814.030494	9510.714136	0.716458343	0.5254463	-23453.30657	37081.36756	-23453.30657	37081.36756

Dependent Variable: Tensile Strength

HDPE Blend: MC and Blend% vs. Tensile Strength

SUMMARY OUTPUT: HDPE Blend

Regression Statistics	
Multiple R	0.700625693
R Square	0.490876362
Adjusted R Square	0.398308428
Standard Error	73.23357345
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	56880.31528	28440.15764	5.302876918	0.024407761
Residual	11	58994.71908	5363.15628		
Total	13	115875.0344			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1574.696399	103.5619433	15.20535777	9.87588E-09	1346.758098	1802.634699	1346.758098	1802.634699
Moisture Content (%)	-160.4651193	76.6026716	-2.094771839	0.060142108	-329.0664627	8.136224144	-329.0664627	8.136224144
Polymer Blend (%)	2.88731775	1.157924466	2.49352858	0.029847685	0.338743183	5.435892317	0.338743183	5.435892317

HDPE Blend: Void% vs. Tensile Strength

SUMMARY OUTPUT: HDPE Blend: Void% vs Tensile

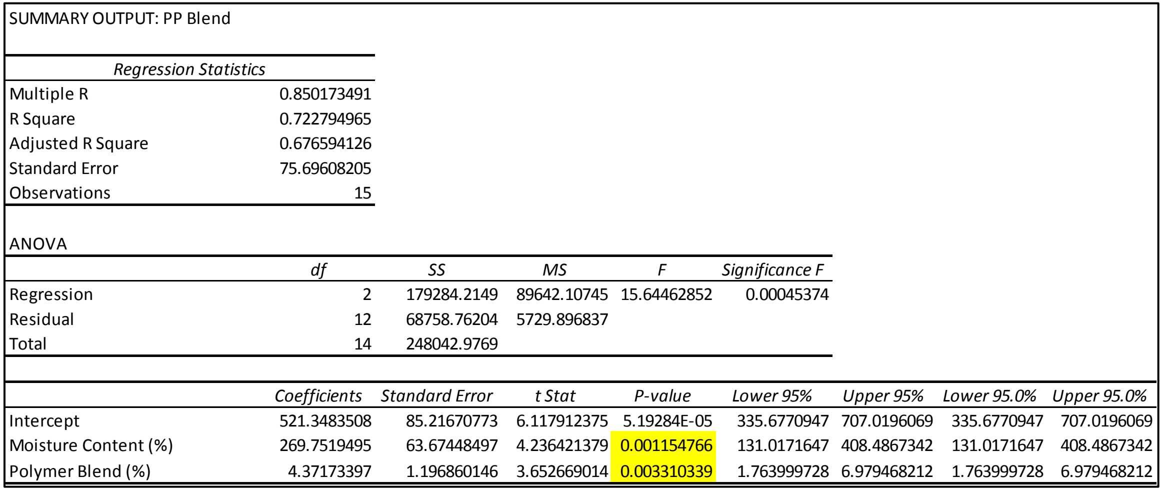
Regression Statistics	
Multiple R	0.475570626
R Square	0.226167421
Adjusted R Square	0.161681372
Standard Error	86.4425998
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	26207.15763	26207.15763	3.507230271	0.085660115
Residual	12	89667.87673	7472.323061		
Total	13	115875.0344			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1631.022349	51.92908402	31.40864853	6.83206E-13	1517.878594	1744.166103	1517.878594	1744.166103
Void %	-4.061040509	2.168478803	-1.872760068	0.085660115	-8.785749945	0.663668927	-8.785749945	0.663668927

PP Blend: MC and Blend% vs. Tensile Strength


SUMMARY OUTPUT: PP Blend

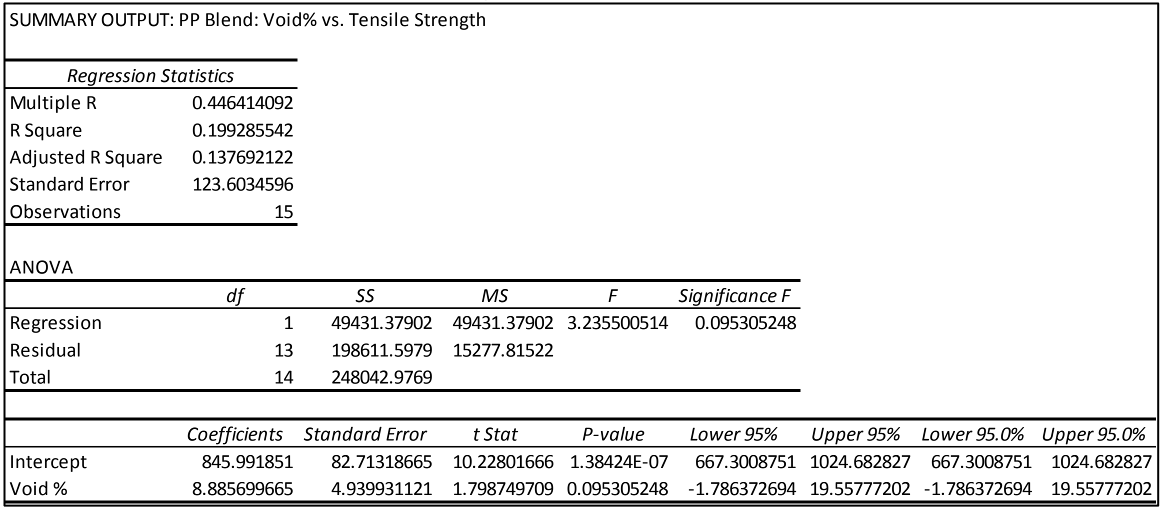
Regression Statistics	
Multiple R	0.850173491
R Square	0.722794965
Adjusted R Square	0.676594126
Standard Error	75.69608205
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	179284.2149	89642.10745	15.64462852	0.00045374
Residual	12	68758.76204	5729.896837		
Total	14	248042.9769			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	521.3483508	85.21670773	6.117912375	5.19284E-05	335.6770947	707.0196069	335.6770947	707.0196069
Moisture Content (%)	269.7519495	63.67448497	4.236421379	0.001154766	131.0171647	408.4867342	131.0171647	408.4867342
Polymer Blend (%)	4.37173397	1.196860146	3.652669014	0.003310339	1.763999728	6.979468212	1.763999728	6.979468212

PP Blend: Void% vs. Tensile Strength


SUMMARY OUTPUT: PP Blend: Void% vs. Tensile Strength

Regression Statistics	
Multiple R	0.446414092
R Square	0.199285542
Adjusted R Square	0.137692122
Standard Error	123.6034596
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	49431.37902	49431.37902	3.235500514	0.095305248
Residual	13	198611.5979	15277.81522		
Total	14	248042.9769			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	845.991851	82.71318665	10.22801666	1.38424E-07	667.3008751	1024.682827	667.3008751	1024.682827
Void %	8.885699665	4.939931121	1.798749709	0.095305248	-1.786372694	19.55777202	-1.786372694	19.55777202

PP Blend: Injection-molded Part Void% vs. Tensile Strength

SUMMARY OUTPUT: PP Blend: Part Void% vs. Tensile Strength

Regression Statistics	
Multiple R	0.078689202
R Square	0.00619199
Adjusted R Square	-0.070254779
Standard Error	137.7028845
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1535.879755	1535.879755	0.080997412	0.780433334
Residual	13	246507.0972	18962.0844		
Total	14	248042.9769			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	988.8142043	40.57336945	24.37101522	3.09634E-12	901.1607687	1076.46764	901.1607687	1076.46764
Molded Part Void %	-1.651891378	5.804247408	-0.284600442	0.780433334	-14.19120555	10.8874228	-14.19120555	10.8874228

PP Blend: ESR% in Melt Cross Section vs. Tensile Strength

SUMMARY OUTPUT: PP Blend: ESR% vs. Tensile Strength

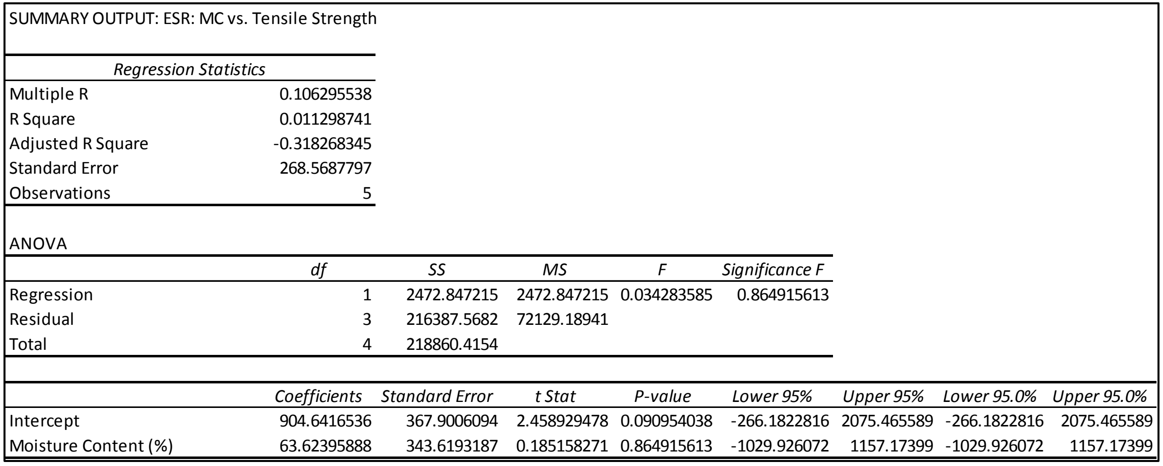
Regression Statistics	
Multiple R	0.532503489
R Square	0.283559966
Adjusted R Square	0.228449194
Standard Error	116.9180906
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	70335.05804	70335.05804	5.145272985	0.04099574
Residual	13	177707.9189	13669.83992		
Total	14	248042.9769			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1079.056126	51.91536698	20.784908	2.33565E-11	966.8997949	1191.212458	966.8997949	1191.212458
ESR%	-8.368404424	3.68925309	-2.268319419	0.04099574	-16.33855116	-0.398257683	-16.33855116	-0.398257683

Unblended ESR: MC and Blend% vs. Tensile Strength



SUMMARY OUTPUT: ESR: MC vs. Tensile Strength

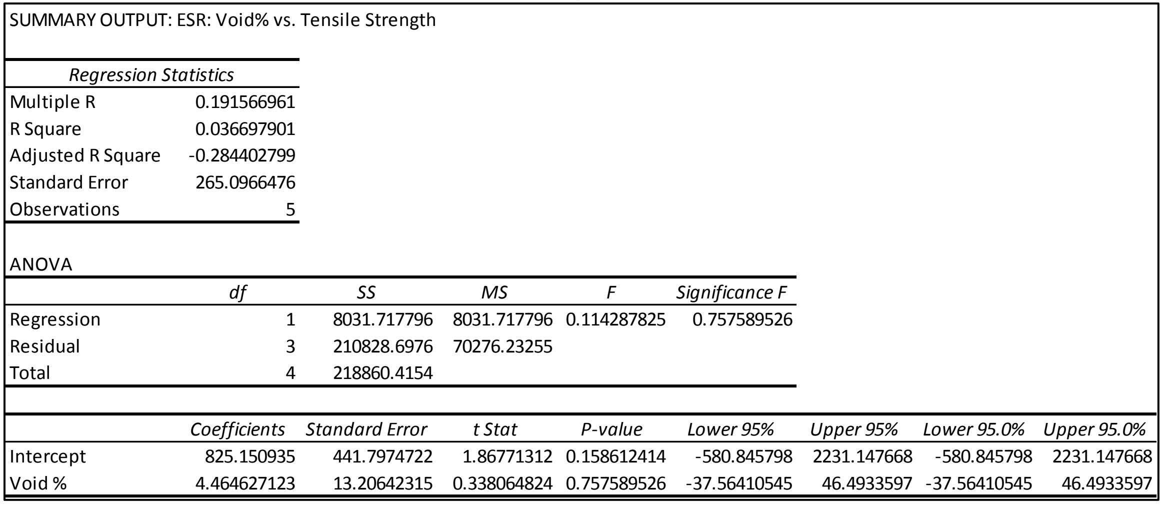
Regression Statistics	
Multiple R	0.106295538
R Square	0.011298741
Adjusted R Square	-0.318268345
Standard Error	268.5687797
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2472.847215	2472.847215	0.034283585	0.864915613
Residual	3	216387.5682	72129.18941		
Total	4	218860.4154			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	904.6416536	367.9006094	2.458929478	0.090954038	-266.1822816	2075.465589	-266.1822816	2075.465589
Moisture Content (%)	63.62395888	343.6193187	0.185158271	0.864915613	-1029.926072	1157.17399	-1029.926072	1157.17399

Unblended ESR: Void% vs. Tensile Strength



SUMMARY OUTPUT: ESR: Void% vs. Tensile Strength

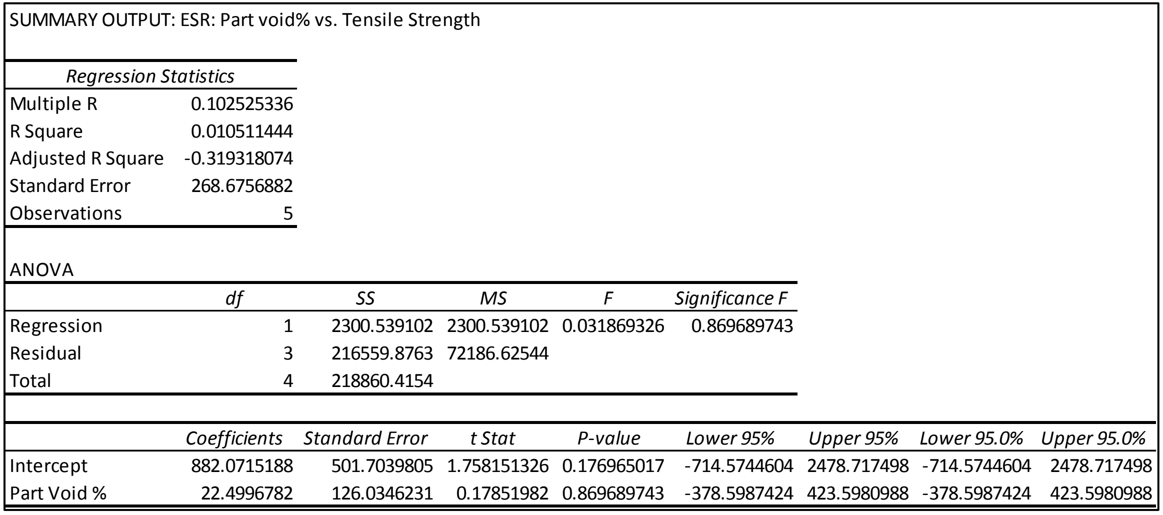
Regression Statistics	
Multiple R	0.191566961
R Square	0.036697901
Adjusted R Square	-0.284402799
Standard Error	265.0966476
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8031.717796	8031.717796	0.114287825	0.757589526
Residual	3	210828.6976	70276.23255		
Total	4	218860.4154			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	825.150935	441.7974722	1.86771312	0.158612414	-580.845798	2231.147668	-580.845798	2231.147668
Void %	4.464627123	13.20642315	0.338064824	0.757589526	-37.56410545	46.4933597	-37.56410545	46.4933597

Unblended ESR: Injection-molded Part Void% vs. Tensile Strength



SUMMARY OUTPUT: ESR: Part void% vs. Tensile Strength

Regression Statistics	
Multiple R	0.102525336
R Square	0.010511444
Adjusted R Square	-0.319318074
Standard Error	268.6756882
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2300.539102	2300.539102	0.031869326	0.869689743
Residual	3	216559.8763	72186.62544		
Total	4	218860.4154			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	882.0715188	501.7039805	1.758151326	0.176965017	-714.5744604	2478.717498	-714.5744604	2478.717498
Part Void %	22.4996782	126.0346231	0.17851982	0.869689743	-378.5987424	423.5980988	-378.5987424	423.5980988

Dependent Variable: Impact Energy

HDPE Blend: MC and Blend% vs. Impact Energy

SUMMARY OUTPUT: HDPE Blend: MC vs. Impact Energy

Regression Statistics	
Multiple R	0.919230499
R Square	0.84498471
Adjusted R Square	0.816800112
Standard Error	1.080060923
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	69.94610013	34.97305007	29.98037097	3.5242E-05
Residual	11	12.83184758	1.166531598		
Total	13	82.77794771			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	29.41324504	1.527348767	19.25771355	8.01563E-10	26.05157307	32.77491701	26.05157307	32.77491701
Moisture Content (%)	-1.464687861	1.129748943	-1.296471991	0.221351141	-3.951248521	1.021872798	-3.951248521	1.021872798
Polymer Blend (%)	-0.13037	0.017077263	-7.634127475	1.01655E-05	-0.167956802	-0.092783198	-0.167956802	-0.092783198

HDPE Blend: Void% vs. Impact Energy

SUMMARY OUTPUT: HDPE Blends: Void% vs. Impact Energy

Regression Statistics	
Multiple R	0.129822589
R Square	0.016853905
Adjusted R Square	-0.065074937
Standard Error	2.60420839
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.395131635	1.395131635	0.205713938	0.65824065
Residual	12	81.38281608	6.78190134		
Total	13	82.77794771			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	21.93161604	1.564438791	14.01883933	8.40249E-09	18.52299674	25.34023535	18.52299674	25.34023535
Void %	-0.029630225	0.065328561	-0.453556985	0.65824065	-0.171968933	0.112708482	-0.171968933	0.112708482

PP Blend: MC and Blend% vs. Impact Energy

SUMMARY OUTPUT: PP Blend: MC vs. Impact Energy

Regression Statistics	
Multiple R	0.641026258
R Square	0.410914663
Adjusted R Square	0.312733774
Standard Error	1.338096516
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	14.98751229	7.493756146	4.185281528	0.041789702
Residual	12	21.48602744	1.790502287		
Total	14	36.47353973			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	25.33131069	1.506394739	16.81585181	1.04518E-09	22.04915851	28.61346287	22.04915851	28.61346287
Moisture Content (%)	-1.065902465	1.125588065	-0.946973852	0.362332069	-3.518348182	1.386543252	-3.518348182	1.386543252
Polymer Blend (%)	-0.05784	0.021157164	-2.733825814	0.018137553	-0.103937499	-0.011742501	-0.103937499	-0.011742501

PP Blend: Void% vs. Impact Energy

SUMMARY OUTPUT: PP Blend: Void% vs. Impact Energy

Regression Statistics	
Multiple R	0.034739685
R Square	0.001206846
Adjusted R Square	-0.075623397
Standard Error	1.673998479
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.044017934	0.044017934	0.015707951	0.902178667
Residual	13	36.4295218	2.802270908		
Total	14	36.47353973			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	21.60739231	1.12020933	19.28870947	5.99535E-11	19.18732718	24.02745743	19.18732718	24.02745743
Void %	-0.008385039	0.066902959	-0.125331365	0.902178667	-0.152920095	0.136150016	-0.152920095	0.136150016

PP Blend: Injection-molded Part vs. Impact Energy

SUMMARY OUTPUT: PP Blend: Part Void% vs. Impact Energy

Regression Statistics	
Multiple R	0.094771789
R Square	0.008981692
Adjusted R Square	-0.067250486
Standard Error	1.667470347
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.327594098	0.327594098	0.11782022	0.736898175
Residual	13	36.14594564	2.780457357		
Total	14	36.47353973			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	21.39662283	0.491310626	43.55009171	1.78814E-15	20.33521075	22.45803491	20.33521075	22.45803491
Molded Part Void %	0.024125199	0.070284733	0.343249501	0.736898175	-0.127715734	0.175966133	-0.127715734	0.175966133

PP Blend: ESR% in Melt Cross Section vs. Tensile Strength

SUMMARY OUTPUT: PP Blend: ESR% in Melt Cross Section vs. Tensile Strength

Regression Statistics	
Multiple R	0.071238216
R Square	0.005074883
Adjusted R Square	-0.071457818
Standard Error	1.670753878
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.185098964	0.185098964	0.066310001	0.80081832
Residual	13	36.28844077	2.791418521		
Total	14	36.47353973			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	21.32244791	0.741868091	28.74156224	3.76253E-13	19.71973934	22.92515648	19.71973934	22.92515648
ESR%	0.01357559	0.052719249	0.257507283	0.80081832	-0.100317422	0.127468603	-0.100317422	0.127468603

ESR Blend: MC vs. Impact Energy

SUMMARY OUTPUT: ESR

Regression Statistics	
Multiple R	0.785414845
R Square	0.616876479
Adjusted R Square	0.489168639
Standard Error	0.058494004
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.016527355	0.016527355	4.830372814	0.115407867
Residual	3	0.010264645	0.003421548		
Total	4	0.026792			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	24.67445783	0.080128374	307.9365855	7.55215E-08	24.41945358	24.92946208	24.41945358	24.92946208
Moisture Content (%)	-0.164484023	0.074839934	-2.197810914	0.115407867	-0.402658093	0.073690047	-0.402658093	0.073690047

ESR Blend: Void% vs. Impact Energy

SUMMARY OUTPUT: ESR: Void% vs. Impact Energy

Regression Statistics	
Multiple R	0.677437413
R Square	0.458921448
Adjusted R Square	0.278561931
Standard Error	0.069513971
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.012295423	0.012295423	2.544481462	0.208947123
Residual	3	0.014496577	0.004832192		
Total	4	0.026792			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	24.68601738	0.11584868	213.0884646	2.27906E-07	24.31733518	25.05469959	24.31733518	25.05469959
Void %	-0.005523988	0.003463005	-1.595143085	0.208947123	-0.016544814	0.005496838	-0.016544814	0.005496838

ESR Blend: Injection-molded Part Void% vs. Impact Energy

SUMMARY OUTPUT: Part Void % and Impact Energy

Regression Statistics	
Multiple R	0.048696252
R Square	0.002371325
Adjusted R Square	-0.330171567
Standard Error	0.09439009
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.35325E-05	6.35325E-05	0.007130884	0.93802252
Residual	3	0.026728467	0.008909489		
Total	4	0.026792			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	24.49354924	0.176256677	138.9652275	8.21621E-07	23.93262183	25.05447665	23.93262183	25.05447665
Part Void %	0.003739036	0.04427799	0.084444564	0.93802252	-0.13717329	0.144651362	-0.13717329	0.144651362

APPENDIX C: TENSILE TEST DATA

Polymer	Blend%	MC%	Sample #	Young's Modulus (psi)	Max Tensile Strength (psi)	Impact Energy (ft-lb)
PP	30% PP	0.57% MC	1	153276	778	24.44
PP	30% PP	0.57% MC	2	153096	773	24.56
PP	30% PP	0.57% MC	3	152301	817	24.32
PP	30% PP	0.57% MC	4	151458	709	24.31
PP	30% PP	0.57% MC	5	148365	723	24.40
PP	50% PP	0.57% MC	1	109100	849	23.32
PP	50% PP	0.57% MC	2	127843	754	23.49
PP	50% PP	0.57% MC	3	135608	786	18.36
PP	50% PP	0.57% MC	4	115880	871	18.42
PP	50% PP	0.57% MC	5	131679	775	23.47
PP	70% PP	0.57% MC	1	115411	832	23.50
PP	70% PP	0.57% MC	2	123093	1045	23.58
PP	70% PP	0.57% MC	3	114557	1114	23.63
PP	70% PP	0.57% MC	4	112130	995	23.63
PP	70% PP	0.57% MC	5	112367	1039	18.66
PP	30% PP	0.69% MC	1	139546	880	23.32
PP	30% PP	0.69% MC	2	134698	798	23.44
PP	30% PP	0.69% MC	3	141434	876	23.42
PP	30% PP	0.69% MC	4	161039	878	23.53
PP	30% PP	0.69% MC	5	148561	846	6.12
PP	50% PP	0.69% MC	1	123496	796	23.45
PP	50% PP	0.69% MC	2	135810	788	23.52
PP	50% PP	0.69% MC	3	75195	767	18.66
PP	50% PP	0.69% MC	4	125573	911	23.55
PP	50% PP	0.69% MC	5	131391	826	18.60
PP	70% PP	0.69% MC	1	93630	1147	23.63
PP	70% PP	0.69% MC	2	119389	1126	18.61
PP	70% PP	0.69% MC	3	124409	991	18.49
PP	70% PP	0.69% MC	4	122672	1051	18.64
PP	70% PP	0.69% MC	5	103742	1204	23.49
PP	30% PP	0.79% MC	1	144439	965	22.94
PP	30% PP	0.79% MC	2	141368	945	22.62
PP	30% PP	0.79% MC	3	139521	878	22.63
PP	30% PP	0.79% MC	4	139646	869	22.72
PP	30% PP	0.79% MC	5	120406	786	22.77

Polymer	Blend%	MC%	Sample #	Young's Modulus (psi)	Max Tensile Strength (psi)	Impact Energy (ft-lb)
PP	50% PP	0.79% MC	1	130846	926	23.00
PP	50% PP	0.79% MC	2	139183	1024	18.06
PP	50% PP	0.79% MC	3	117503	1018	17.91
PP	50% PP	0.79% MC	4	130187	905	22.86
PP	50% PP	0.79% MC	5	120816	938	23.03
PP	70% PP	0.79% MC	1	125453	1080	23.67
PP	70% PP	0.79% MC	2	122469	997	18.65
PP	70% PP	0.79% MC	3	105867	1087	18.50
PP	70% PP	0.79% MC	4	114073	1166	18.82
PP	70% PP	0.79% MC	5	130127	919	23.68
PP	30% PP	1.02% MC	1	140167	1116	22.96
PP	30% PP	1.02% MC	2	142824	1078	22.78
PP	30% PP	1.02% MC	3	132663	1122	22.74
PP	30% PP	1.02% MC	4	139014	1108	22.80
PP	30% PP	1.02% MC	5	135050	1060	22.80
PP	50% PP	1.02% MC	1	120189	1116	23.35
PP	50% PP	1.02% MC	2	122029	947	23.39
PP	50% PP	1.02% MC	3	129452	978	18.72
PP	50% PP	1.02% MC	4	123877	1005	23.40
PP	50% PP	1.02% MC	5	121394	976	18.49
PP	70% PP	1.02% MC	1	110120	1072	22.69
PP	70% PP	1.02% MC	2	110559	1252	17.81
PP	70% PP	1.02% MC	3	115091	1080	17.72
PP	70% PP	1.02% MC	4	121847	1066	17.75
PP	70% PP	1.02% MC	5	115858	1072	22.80
PP	30% PP	1.44% MC	1	138093	1037	23.10
PP	30% PP	1.44% MC	2	128390	1080	23.13
PP	30% PP	1.44% MC	3	144662	934	23.16
PP	30% PP	1.44% MC	4	138933	1037	23.02
PP	30% PP	1.44% MC	5	#VALUE!	No data	23.13
PP	50% PP	1.44% MC	1	131903	1095	23.35
PP	50% PP	1.44% MC	2	124597	1032	23.27
PP	50% PP	1.44% MC	3	133126	1035	23.19
PP	50% PP	1.44% MC	4	127160	1028	23.27
PP	50% PP	1.44% MC	5	126043	997	18.23
PP	70% PP	1.44% MC	1	141549	1312	17.76
PP	70% PP	1.44% MC	2	135464	1409	17.83
PP	70% PP	1.44% MC	3	139816	1379	17.89
PP	70% PP	1.44% MC	4	135479	1250	17.80
PP	70% PP	1.44% MC	5	135825	1319	18.09
HDPE	30% PP	0.59% MC	1	179411	1507	24.10
HDPE	30% PP	0.59% MC	2	186185	1638	24.26
HDPE	30% PP	0.59% MC	3	174112	1503	24.30
HDPE	30% PP	0.59% MC	4	165082	1570	24.22
HDPE	30% PP	0.59% MC	5	No Data	No Data	24.27
HDPE	50% PP	0.59% MC	1	No Data	No Data	No Data
HDPE	50% PP	0.59% MC	2	No Data	No Data	No Data

Polymer	Blend%	MC%	Sample #	Young's Modulus (psi)	Max Tensile Strength (psi)	Impact Energy (ft-lb)
HDPE	50% PP	0.59% MC	3	No Data	No Data	No Data
HDPE	50% PP	0.59% MC	4	No Data	No Data	No Data
HDPE	50% PP	0.59% MC	5	No Data	No Data	No Data
HDPE	70% PP	0.59% MC	1	133912	1601	18.99
HDPE	70% PP	0.59% MC	2	136325	1628	19.04
HDPE	70% PP	0.59% MC	3	140521	1630	19.16
HDPE	70% PP	0.59% MC	4	137892	1657	19.11
HDPE	70% PP	0.59% MC	5	135674	1707	19.02
HDPE	30% PP	0.93% MC	1	168331	1628	23.76
HDPE	30% PP	0.93% MC	2	170420	1427	23.71
HDPE	30% PP	0.93% MC	3	158955	1551	23.96
HDPE	30% PP	0.93% MC	4	163448	1584	23.93
HDPE	30% PP	0.93% MC	5	159825	1542	23.73
HDPE	50% PP	0.93% MC	1	156293	1735	23.84
HDPE	50% PP	0.93% MC	2	149899	1684	24.03
HDPE	50% PP	0.93% MC	3	155155	1663	23.92
HDPE	50% PP	0.93% MC	4	155172	1618	23.85
HDPE	50% PP	0.93% MC	5	150440	1640	23.81
HDPE	70% PP	0.93% MC	1	128114	1668	18.66
HDPE	70% PP	0.93% MC	2	132358	1638	18.64
HDPE	70% PP	0.93% MC	3	128723	1626	18.63
HDPE	70% PP	0.93% MC	4	134880	1638	18.56
HDPE	70% PP	0.93% MC	5	130426	1712	18.69
HDPE	30% PP	1.13% MC	1	150184	1509	24.05
HDPE	30% PP	1.13% MC	2	153698	1379	23.88
HDPE	30% PP	1.13% MC	3	141699	1429	24.06
HDPE	30% PP	1.13% MC	4	151814	1348	24.13
HDPE	30% PP	1.13% MC	5	No Data	No data	24.18
HDPE	50% PP	1.13% MC	1	140986	1440	18.90
HDPE	50% PP	1.13% MC	2	138982	1448	18.76
HDPE	50% PP	1.13% MC	3	136220	1496	24.02
HDPE	50% PP	1.13% MC	4	138677	1406	18.72
HDPE	50% PP	1.13% MC	5	132588	1438	18.88
HDPE	70% PP	1.13% MC	1	124743	1513	18.62
HDPE	70% PP	1.13% MC	2	129003	1507	18.68
HDPE	70% PP	1.13% MC	3	131086	1528	18.89
HDPE	70% PP	1.13% MC	4	131497	1509	18.62
HDPE	70% PP	1.13% MC	5	128010	1561	18.68
HDPE	30% PP	1.27% MC	1	143436	1559	24.19
HDPE	30% PP	1.27% MC	2	127867	1584	24.05
HDPE	30% PP	1.27% MC	3	139283	1517	24.20
HDPE	30% PP	1.27% MC	4	133076	1561	23.80
HDPE	30% PP	1.27% MC	5	138852	1570	24.05
HDPE	50% PP	1.27% MC	1	134913	1618	24.12
HDPE	50% PP	1.27% MC	2	109279	1582	18.83
HDPE	50% PP	1.27% MC	3	132805	1588	18.93
HDPE	50% PP	1.27% MC	4	134577	1588	18.98
HDPE	50% PP	1.27% MC	5	135599	1613	24.07

Polymer	Blend%	MC%	Sample #	Young's Modulus (psi)	Max Tensile Strength (psi)	Impact Energy (ft-lb)
HDPE	70% PP	1.27% MC	1	125856	1666	18.81
HDPE	70% PP	1.27% MC	2	121591	1670	19.03
HDPE	70% PP	1.27% MC	3	118737	1480	19.20
HDPE	70% PP	1.27% MC	4	120015	1628	19.09
HDPE	70% PP	1.27% MC	5	129288	1639	18.93
HDPE	30% PP	1.37% MC	1	152090	1262	24.00
HDPE	30% PP	1.37% MC	2	146869	1459	24.08
HDPE	30% PP	1.37% MC	3	159596	1329	24.27
HDPE	30% PP	1.37% MC	4	147371	1369	24.13
HDPE	30% PP	1.37% MC	5	147581	1415	24.00
HDPE	50% PP	1.37% MC	1	137372	1496	19.07
HDPE	50% PP	1.37% MC	2	127432	1486	18.97
HDPE	50% PP	1.37% MC	3	141758	1453	18.97
HDPE	50% PP	1.37% MC	4	137110	1421	18.88
HDPE	50% PP	1.37% MC	5	118438	1358	18.93
HDPE	70% PP	1.37% MC	1	122327	1597	18.77
HDPE	70% PP	1.37% MC	2	125158	1563	18.74
HDPE	70% PP	1.37% MC	3	130671	1574	18.74
HDPE	70% PP	1.37% MC	4	126705	1584	18.82
HDPE	70% PP	1.37% MC	5	120413	1572	18.82
ESR	Unblended	0.43% MC	1	198404	997	24.59
ESR	Unblended	0.43% MC	2	No Data	No Data	24.67
ESR	Unblended	0.43% MC	3	No Data	No Data	24.49
ESR	Unblended	0.43% MC	4	No Data	No Data	24.56
ESR	Unblended	0.43% MC	5	No Data	No Data	24.52
ESR	Unblended	0.85% MC	1	170029	543	24.57
ESR	Unblended	0.85% MC	2	199292	769	24.43
ESR	Unblended	0.85% MC	3	No Data	No Data	24.55
ESR	Unblended	0.85% MC	4	No Data	No Data	24.65
ESR	Unblended	0.85% MC	5	No Data	No Data	24.58
ESR	Unblended	1.09% MC	1	169082	1183	24.54
ESR	Unblended	1.09% MC	2	No Data	No Data	24.57
ESR	Unblended	1.09% MC	3	No Data	No Data	24.59
ESR	Unblended	1.09% MC	4	No Data	No Data	24.52
ESR	Unblended	1.09% MC	5	No Data	No Data	24.59
ESR	Unblended	1.25% MC	1	159313	1135	24.32
ESR	Unblended	1.25% MC	2	165475	1356	24.39
ESR	Unblended	1.25% MC	3	173288	1285	24.47
ESR	Unblended	1.25% MC	4	156590	993	24.52
ESR	Unblended	1.25% MC	5	161740	1200	24.70
ESR	Unblended	1.44% MC	1	145417	784	24.39
ESR	Unblended	1.44% MC	2	135538	874	24.45
ESR	Unblended	1.44% MC	3	150657	573	24.40
ESR	Unblended	1.44% MC	4	166321	1030	24.35
ESR	Unblended	1.44% MC	5	No Data	No Data	24.29
HDPE	Pure	N/A	1	121740	1720	19.31
HDPE	Pure	N/A	2	113757	1747	19.28
HDPE	Pure	N/A	3	115659	1714	19.24

Polymer	Blend%	MC%	Sample #	Young's Modulus (psi)	Max Tensile Strength (psi)	Impact Energy (ft-lb)
HDPE	Pure	N/A	4	125326	1714	19.20
HDPE	Pure	N/A	5	No Data	No Data	19.26
PP	Pure	N/A	1	109117	1538	19.24
PP	Pure	N/A	2	112541	1563	19.27
PP	Pure	N/A	3	108506	1567	19.14
PP	Pure	N/A	4	98183	1536	19.22
PP	Pure	N/A	5	110772	1572	19.13

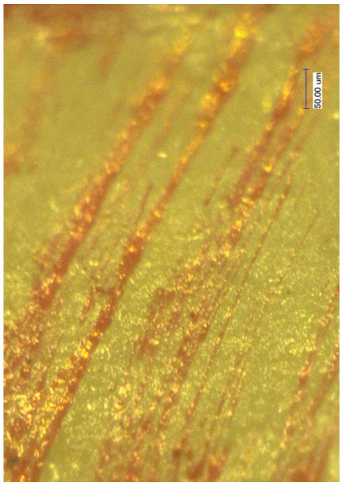
APPENDIX D: MICROSCOPE IMAGES

Extrudate
0.59% MC

Injection-molded Part
0.59% MC

70% HDPE

70% HDPE



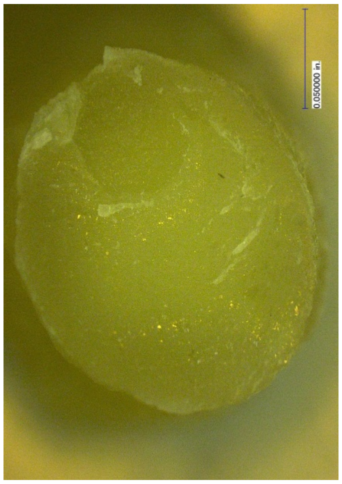
50% HDPE

No Data

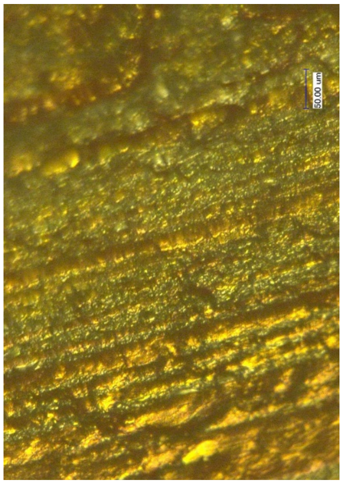
50% HDPE

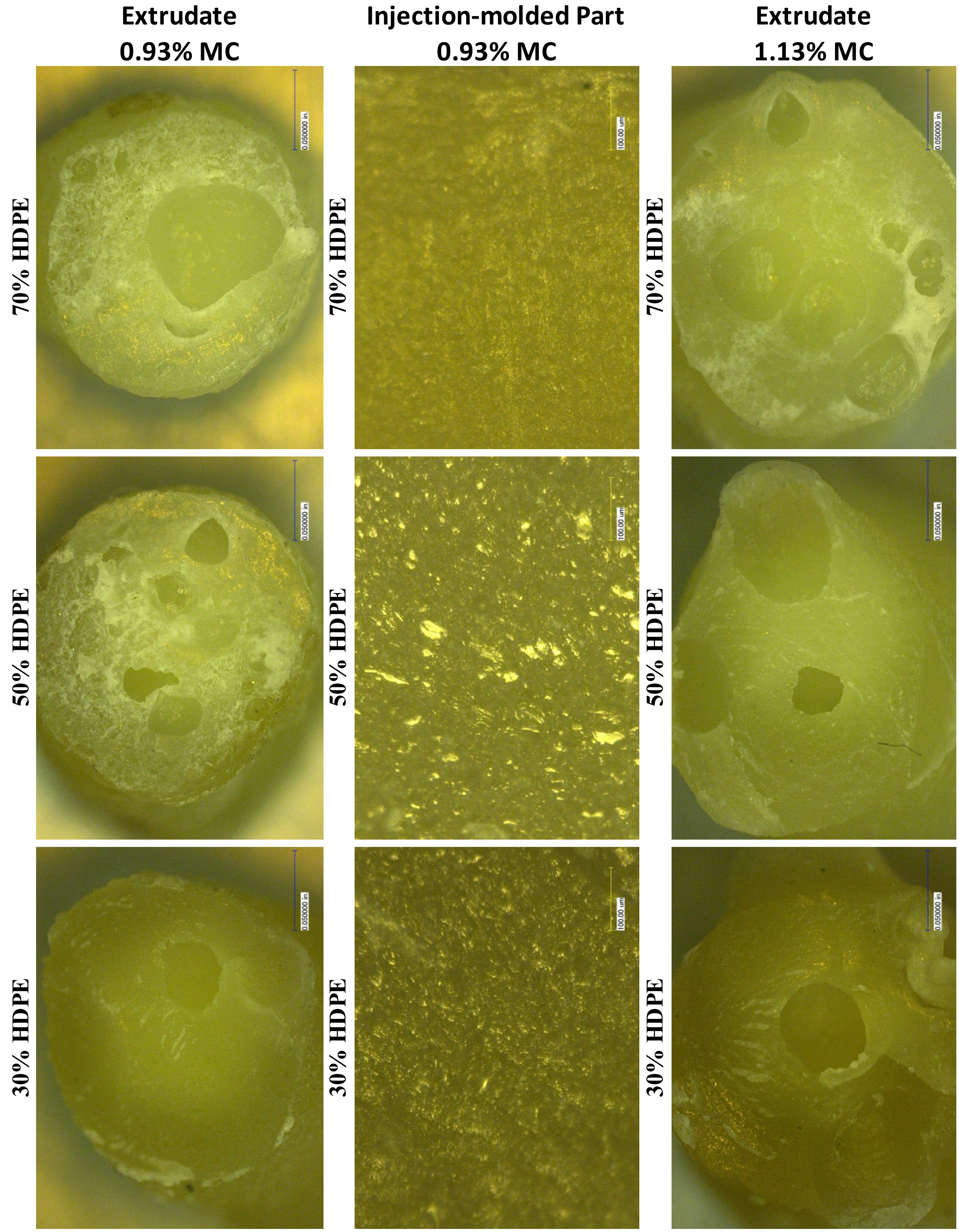
No Data

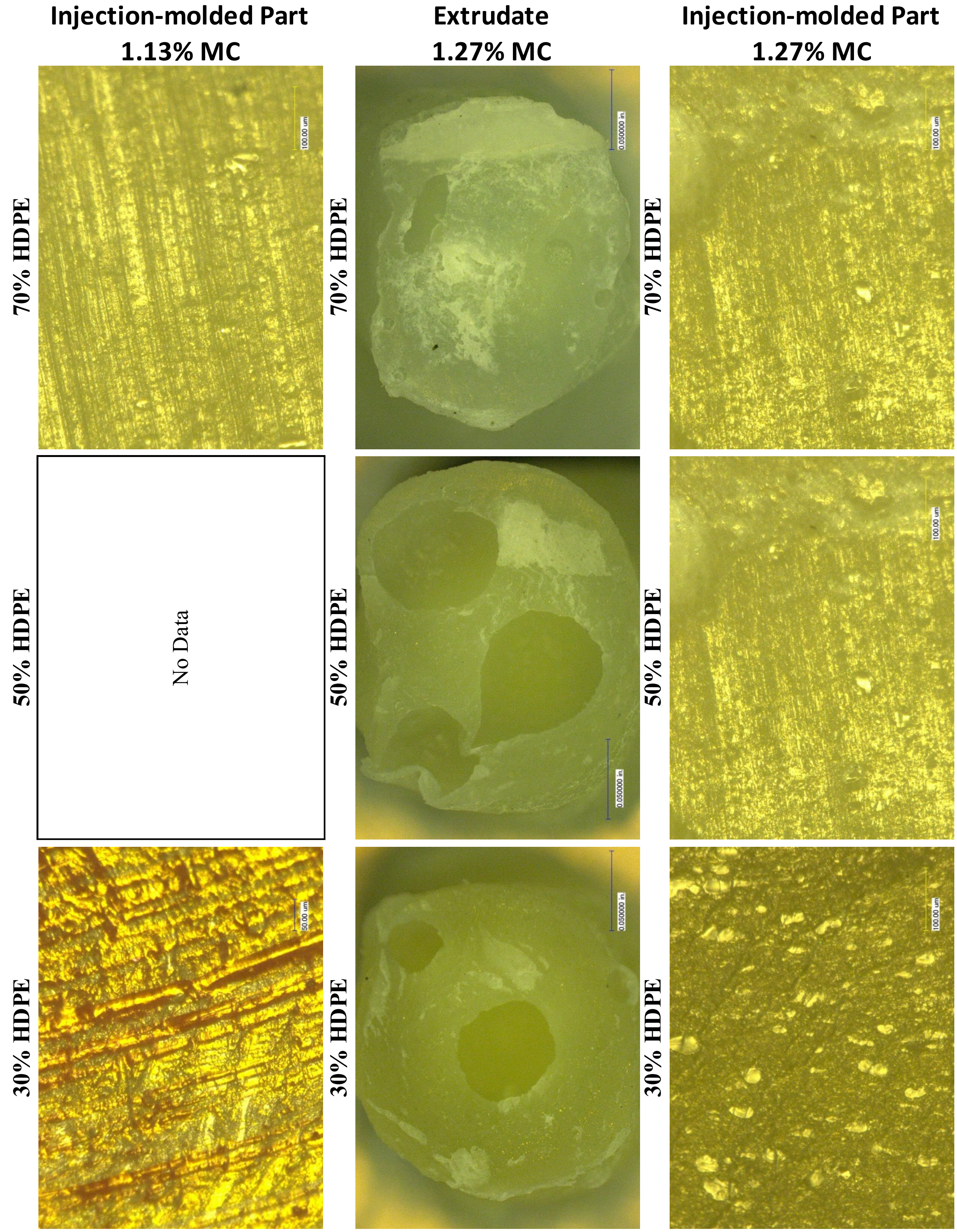
30% HDPE

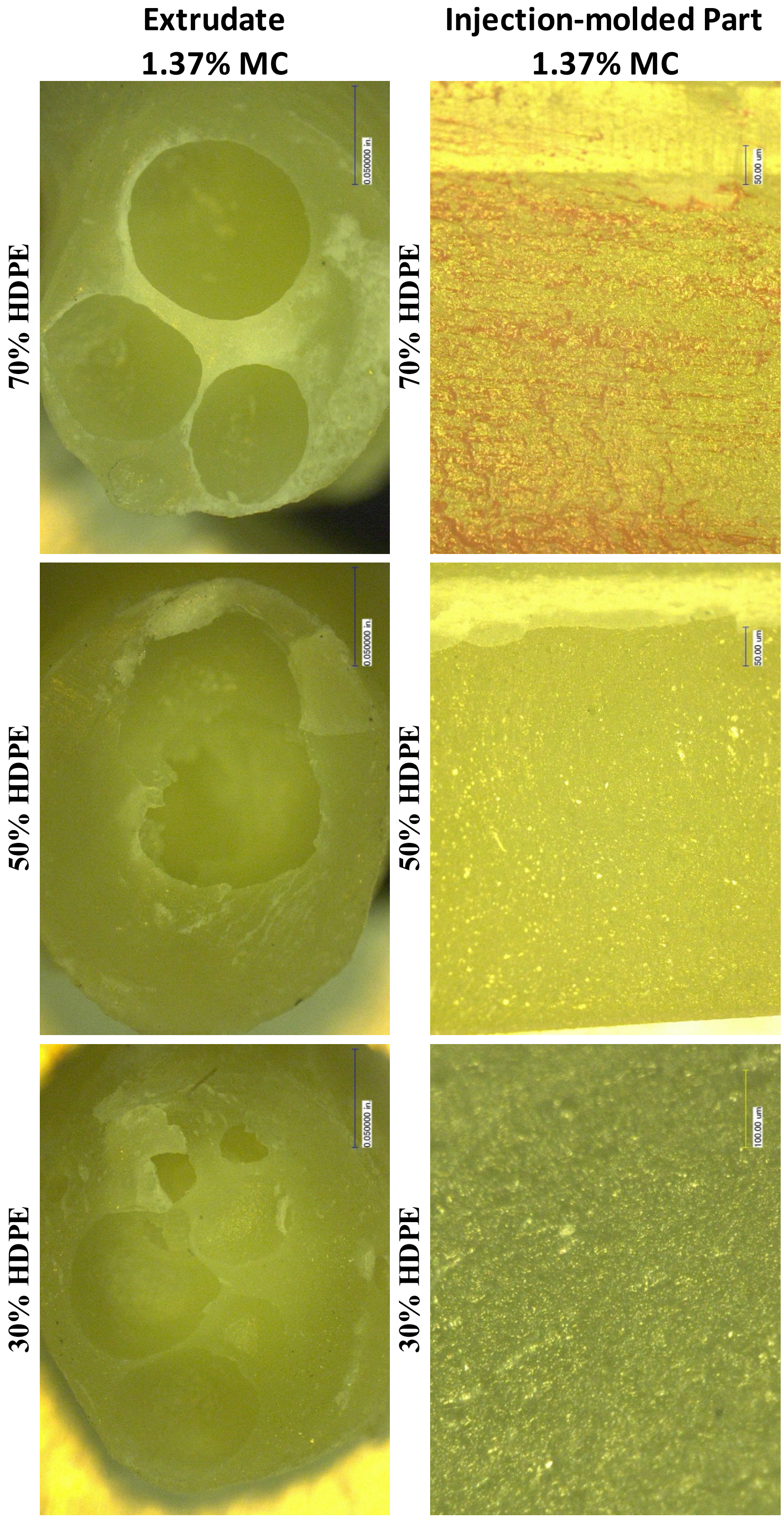


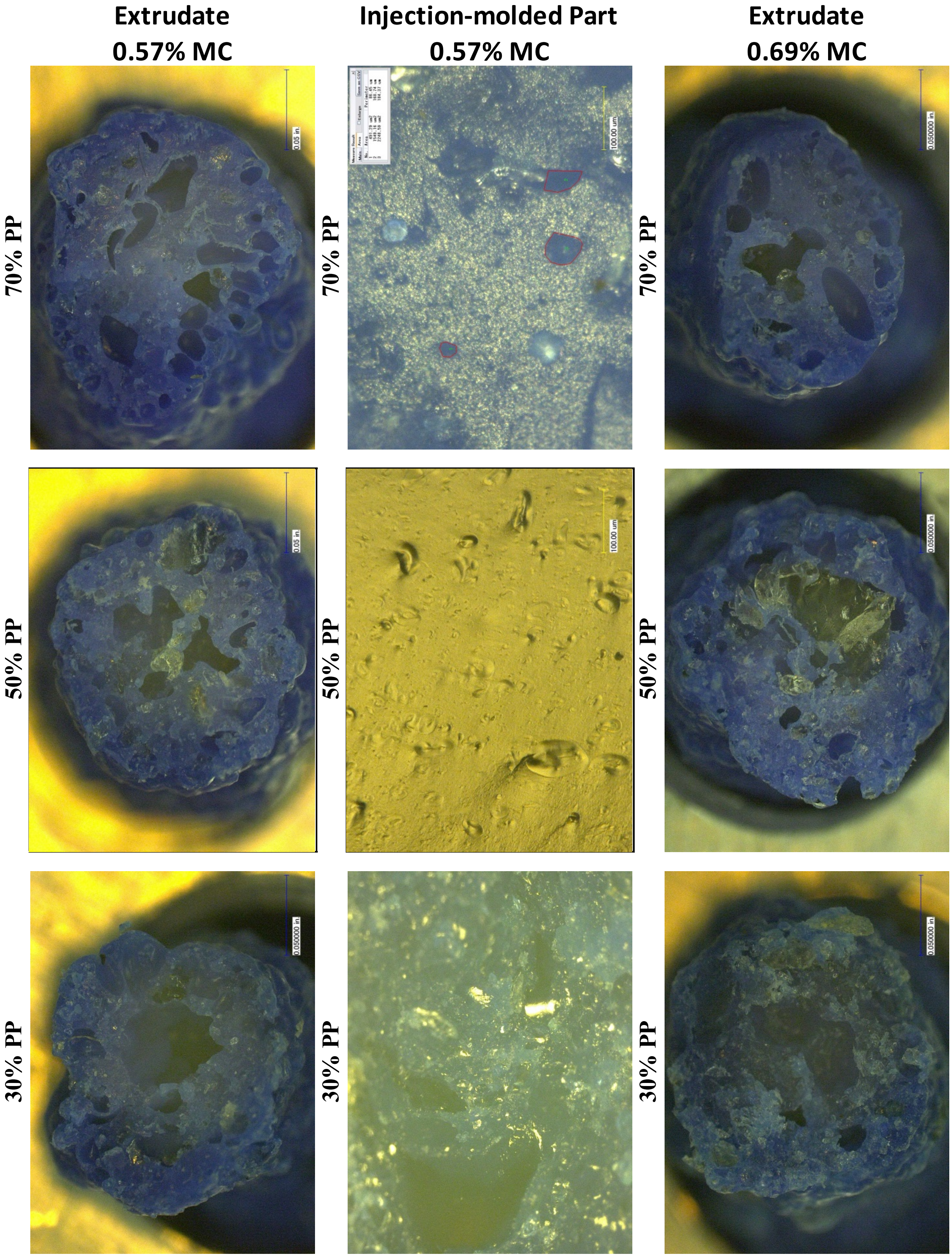
30% HDPE

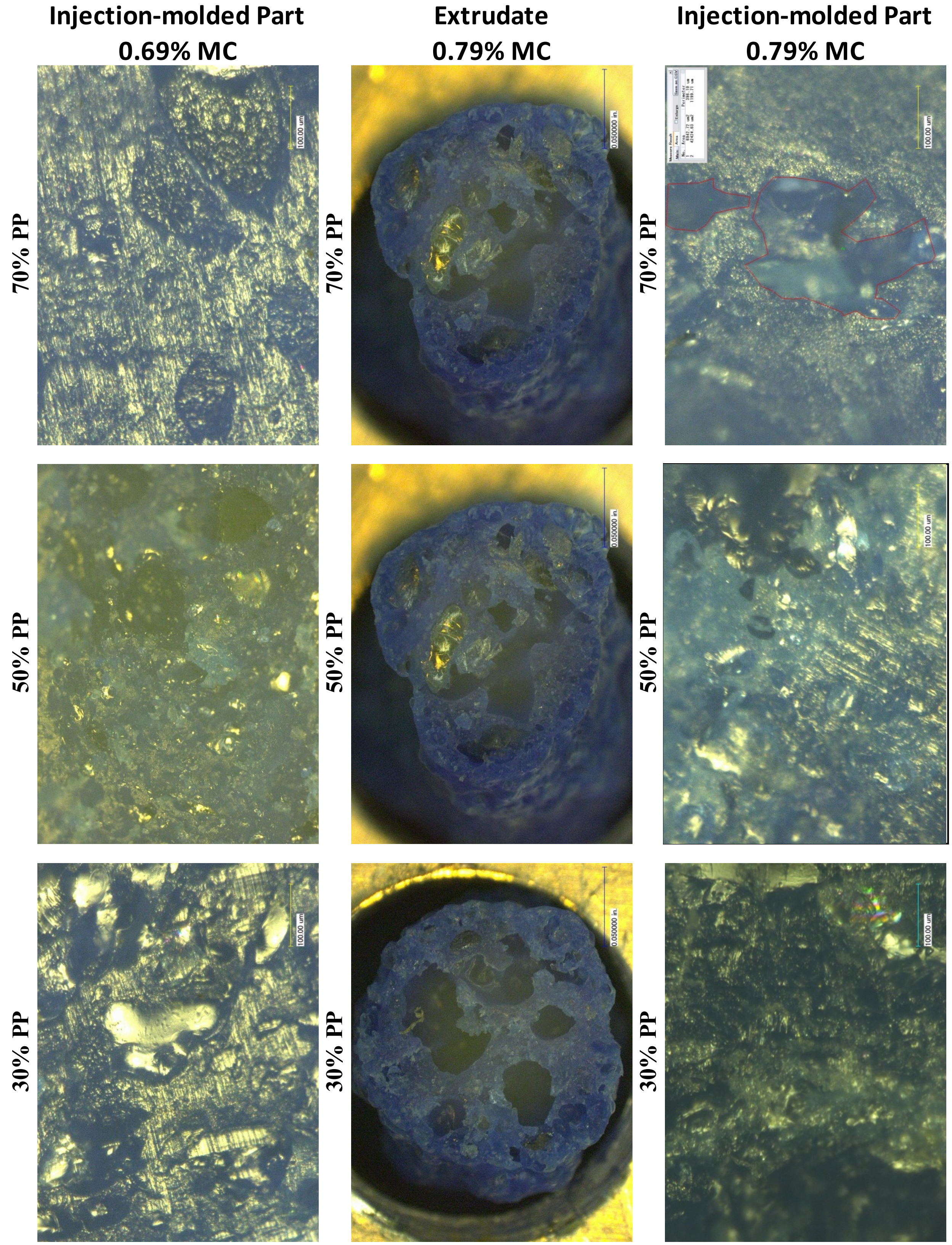


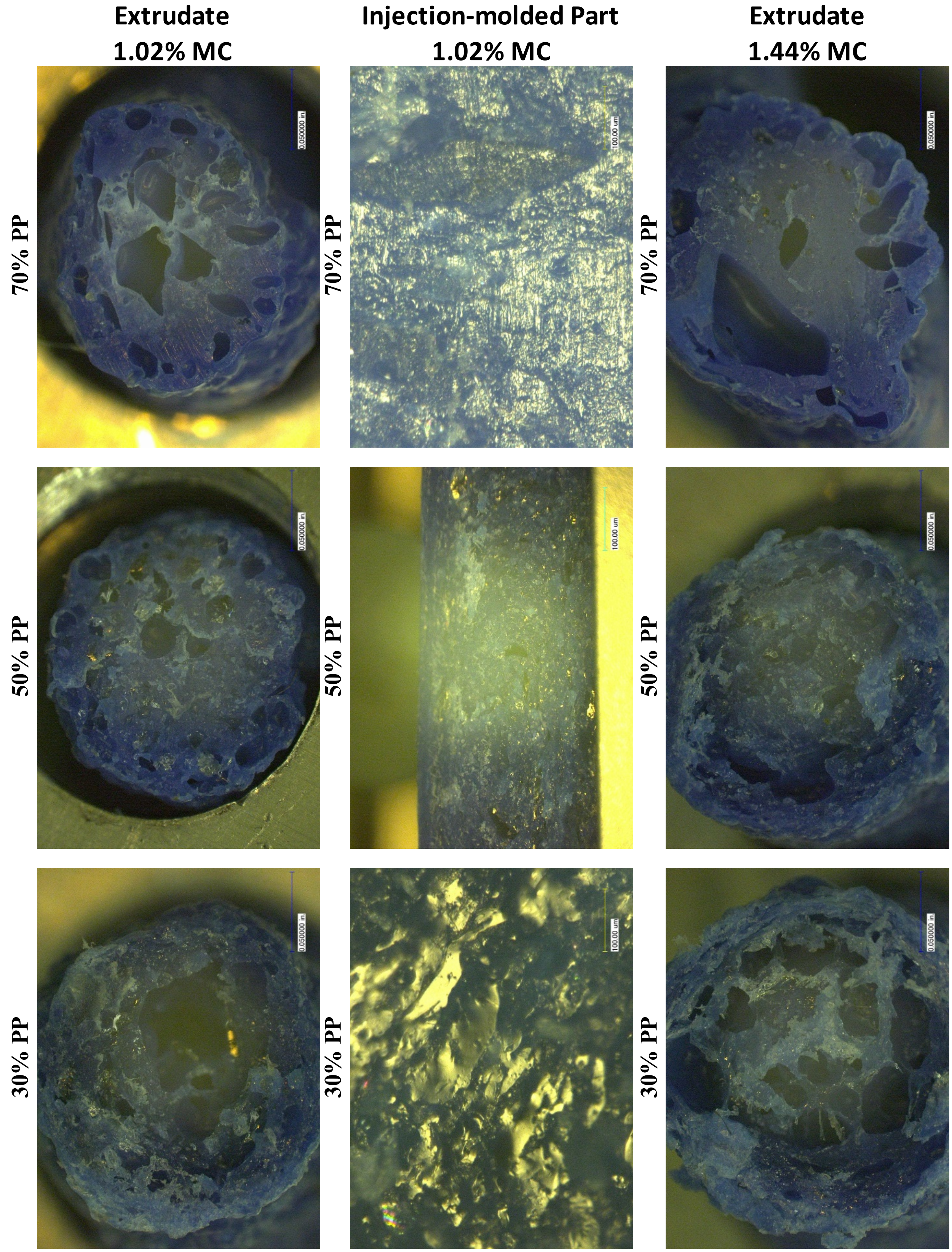

Extrudate
0.93% MC
Injection-molded Part
0.93% MC
Extrudate
1.13% MC
70% HDPE
50% HDPE
30% HDPE
0.050000 in
100.00 um


Injection-molded Part
1.13% MC
Extrudate
1.27% MC
Injection-molded Part
1.27% MC
70% HDPE
50% HDPE
30% HDPE
No Data
100.00 um
0.050000 in
50.00 um


Extrudate
1.37% MC
Injection-molded Part
1.37% MC
70% HDPE
50% HDPE
30% HDPE
0.050000 in
50.00 um
100.00 um

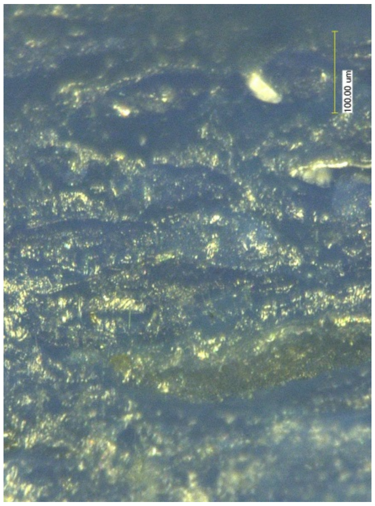

Extrudate
0.57% MC
Injection-molded Part
0.57% MC
Extrudate
0.69% MC
70% PP
50% PP
30% PP
0.05 in
100.00 um
0.050000 in


Injection-molded Part
0.69% MC
Extrudate
0.79% MC
Injection-molded Part
0.79% MC
70% PP
50% PP
30% PP
100.00 um
0.050000 in.

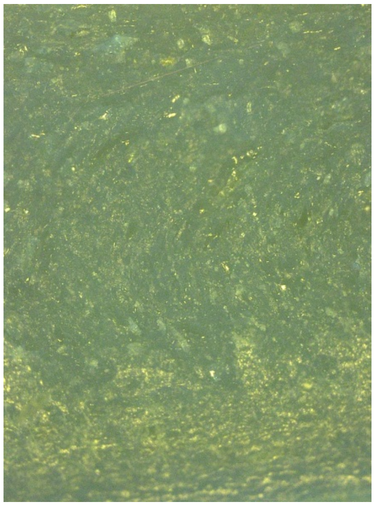

Extrudate
1.02% MC
Injection-molded Part
1.02% MC
Extrudate
1.44% MC
70% PP
50% PP
30% PP
0.050000 in
100.00 um

Injection-molded Part
1.44% MC

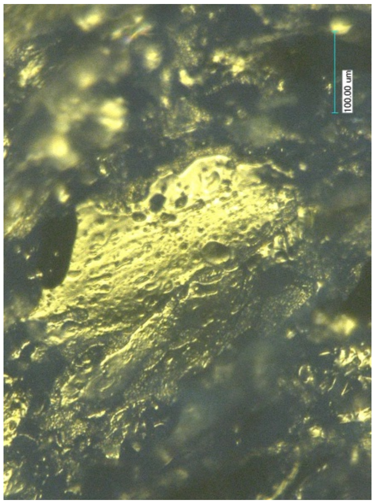
70% PP



50% PP

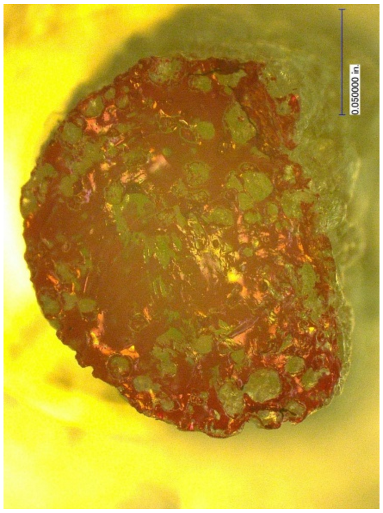


30% PP



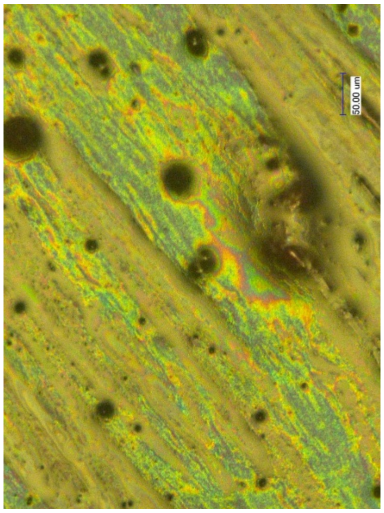
Extrudate
0.43% MC

Unblended TPS



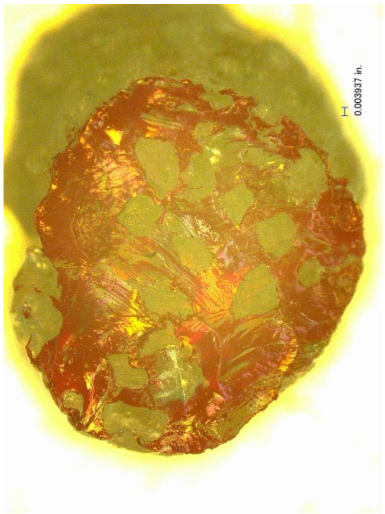
Injection-molded Part
0.43% MC

Unblended TPS



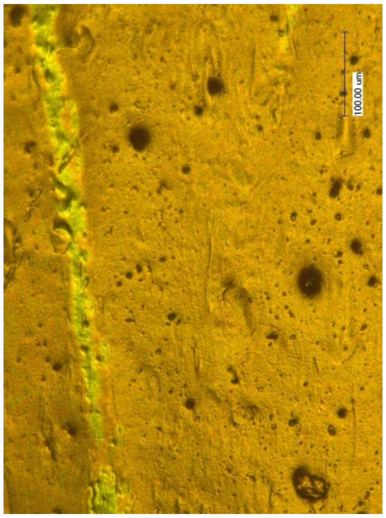
Extrudate
0.85% MC

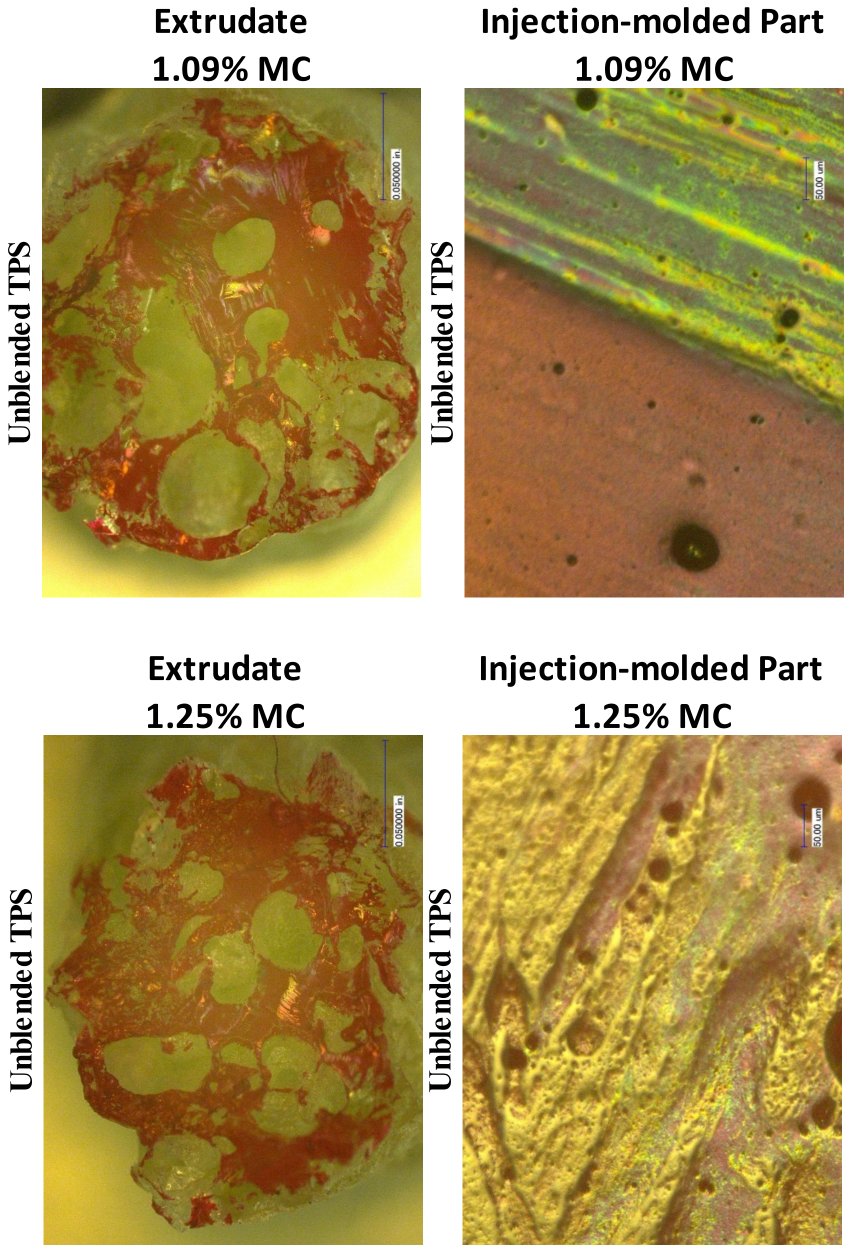
Unblended TPS

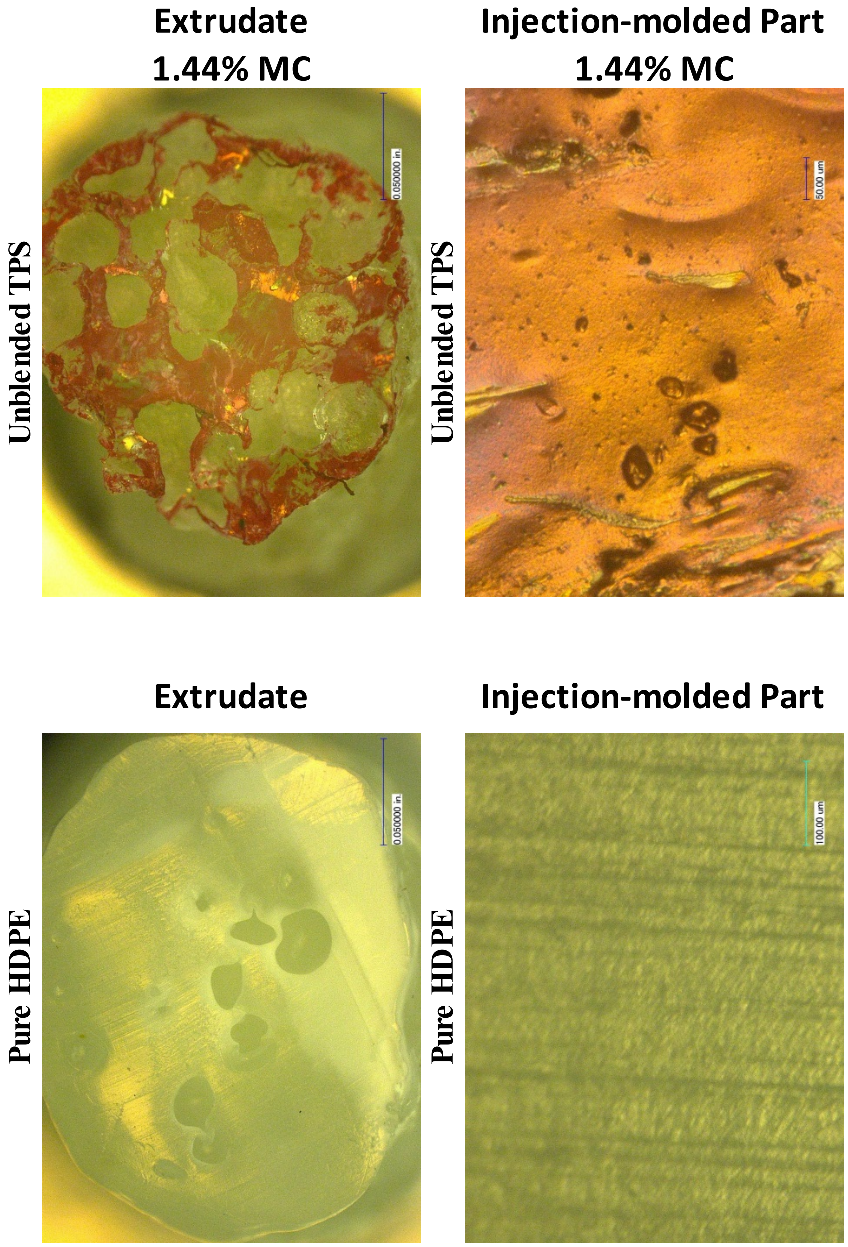


Injection-molded Part
0.85% MC

Unblended TPS

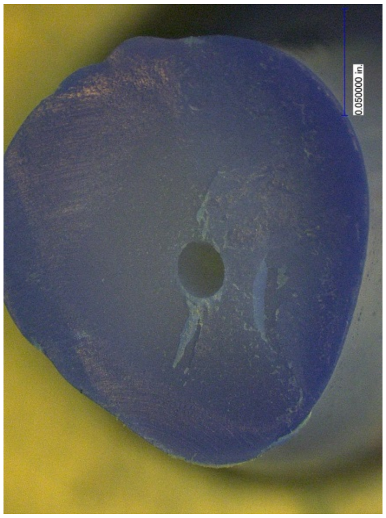



Extrudate
1.09% MC
Injection-molded Part
1.09% MC
Unblended TPS
Unblended TPS
0.050000 in
50.00 um
Extrudate
1.25% MC
Injection-molded Part
1.25% MC
Unblended TPS
Unblended TPS
0.050000 in
50.00 um


Extrudate
1.44% MC
Injection-molded Part
1.44% MC
Unblended TPS
0.050000 in
Unblended TPS
50.00 um
Extrudate
Injection-molded Part
Pure HDPE
0.050000 in
Pure HDPE
100.00 um

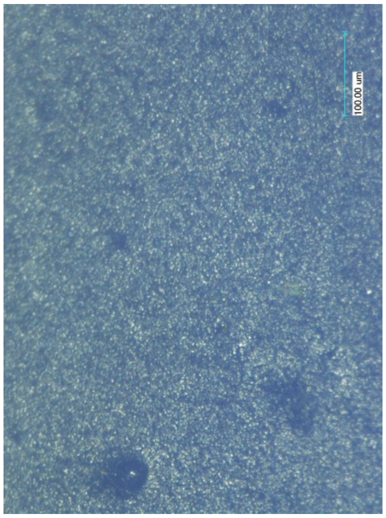
Extrudate

Pure PP



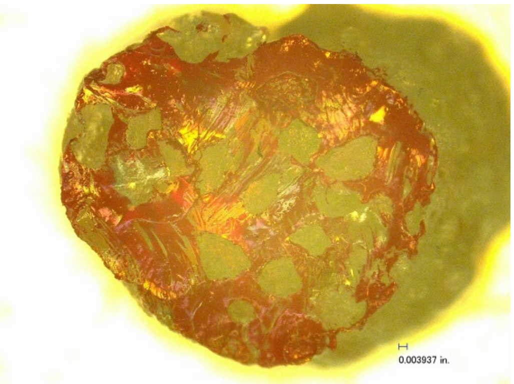
Injection-molded Part

Pure PP



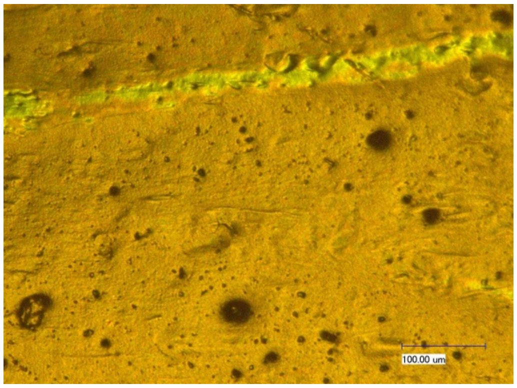
Unblended TPS

Extrudate
0.85% MC



Unblended TPS

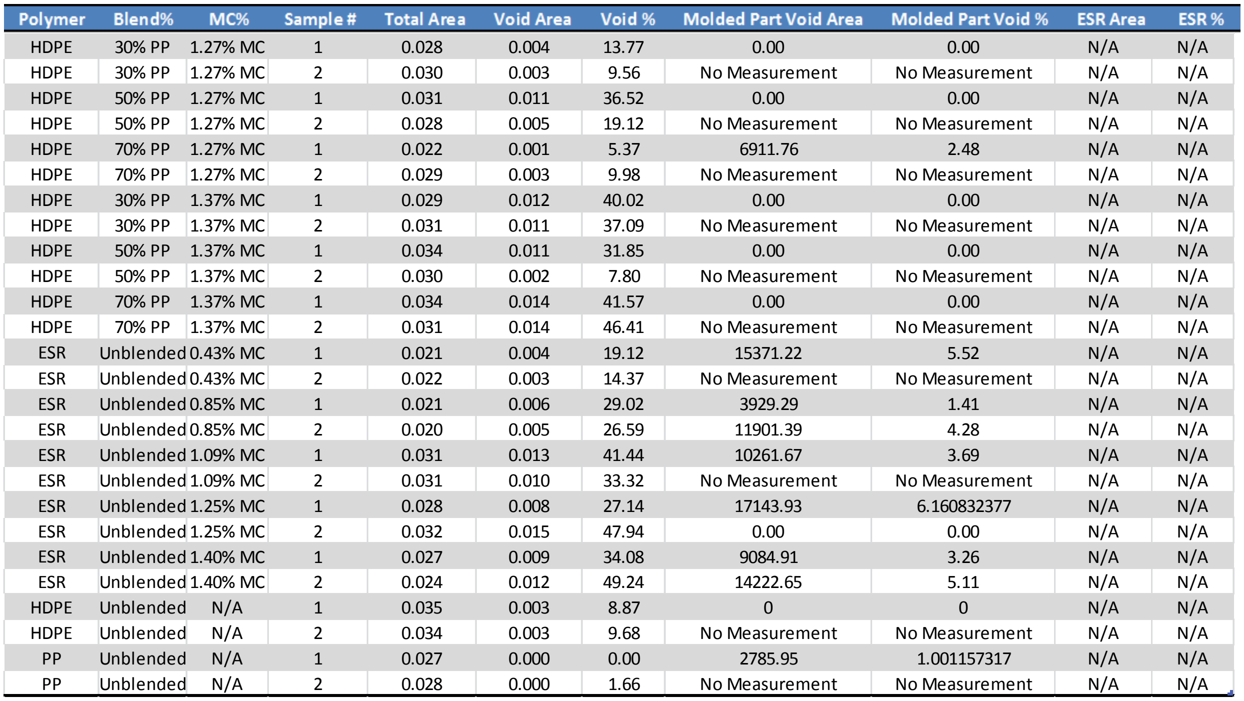
Injection-molded Part
0.85% MC



APPENDIX E: MICROSCOPE DATA

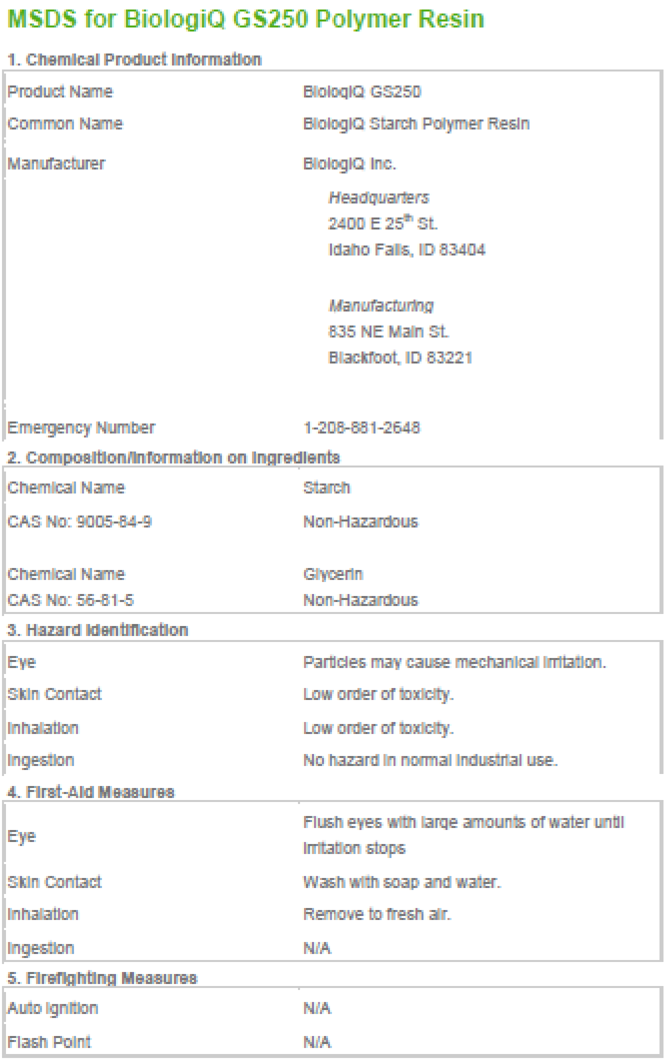
Microscope Data

Polymer	Blend%	MC%	Sample #	Total Area	Void Area	Void %	Molded Part Void Area	Molded Part Void %	ESR Area	ESR %
PP	30% PP	0.57% MC	1	0.020	0.003	15.76	0.00	0.00	0.002199	10.79
PP	30% PP	0.57% MC	2	0.012	0.001	7.29	No Measurement	No Measurement	0.000936	7.49
PP	50% PP	0.57% MC	1	0.020	0.003	12.86	38788.37	13.94	0.002995	14.97
PP	50% PP	0.57% MC	2	0.017	0.001	5.12	No Measurement	No Measurement	0.008665	49.86
PP	70% PP	0.57% MC	1	0.022	0.005	20.35	4289.03	1.54	0.001284	5.71
PP	70% PP	0.57% MC	2	0.020	0.003	13.28	No Measurement	No Measurement	0.005154	26.41
PP	30% PP	0.69% MC	1	0.022	0.003	12.49	0.00	0.00	0.002224	10.26
PP	30% PP	0.69% MC	2	0.017	0.002	13.54	No Measurement	No Measurement	0.00114	6.59
PP	50% PP	0.69% MC	1	0.022	0.001	6.13	0.00	0.00	0.006223	28.39
PP	50% PP	0.69% MC	2	0.021	0.002	7.47	No Measurement	No Measurement	0.002318	11.28
PP	70% PP	0.69% MC	1	0.016	0.004	24.76	0.00	0.00	0.000894	5.68
PP	70% PP	0.69% MC	2	0.024	0.004	18.40	No Measurement	No Measurement	0.001369	5.66
PP	30% PP	0.79% MC	1	0.023	0.007	29.18	1887.84	5.29	0.001655	7.26
PP	30% PP	0.79% MC	2	0.023	0.004	19.28	0.00	0.00	0.002007	8.81
PP	50% PP	0.79% MC	1	0.020	0.003	15.54	0.00	0.00	0.005827	28.57
PP	50% PP	0.79% MC	2	0.025	0.002	6.87	No Measurement	No Measurement	0.005561	21.82
PP	70% PP	0.79% MC	1	0.022	0.003	14.57	49367.35	17.74	0.000314	1.40
PP	70% PP	0.79% MC	2	0.022	0.002	8.45	No Measurement	No Measurement	0.002542	11.57
PP	30% PP	1.02% MC	1	0.028	0.010	34.42	0.00	0.00	0.00109	3.94
PP	30% PP	1.02% MC	2	0.028	0.002	6.87	No Measurement	No Measurement	0.001101	3.88
PP	50% PP	1.02% MC	1	0.022	0.003	11.72	0.00	0.00	0.002031	9.18
PP	50% PP	1.02% MC	2	0.021	0.002	7.25	No Measurement	No Measurement	0.002665	12.45
PP	70% PP	1.02% MC	1	0.020	0.007	34.65	0.00	0.00	0.000403	2.05
PP	70% PP	1.02% MC	2	0.022	0.005	24.10	No Measurement	No Measurement	0.000579	2.66
PP	30% PP	1.44% MC	1	0.033	0.009	28.17	3099.60	14.65	0.000125	0.38
PP	30% PP	1.44% MC	2	0.030	0.005	16.04	No Measurement	No Measurement	0.000544	1.80
PP	50% PP	1.44% MC	1	0.027	0.003	10.74	0.00	0.00	0.001144	4.20
PP	50% PP	1.44% MC	2	0.026	0.002	7.95	No Measurement	No Measurement	0.000351	1.34
PP	70% PP	1.44% MC	1	0.029	0.006	22.55	0.00	0.00	0.000433	1.51
PP	70% PP	1.44% MC	2	0.031	0.002	7.59	No Measurement	No Measurement	0.000179	0.57
HDPE	30% PP	0.59% MC	1	0.023	0.001	3.41	0.00	0.00	N/A	N/A
HDPE	30% PP	0.59% MC	2	0.023	0.003	13.87	No Measurement	No Measurement	N/A	N/A
HDPE	50% PP	0.59% MC	No Data	No Data	No Data	No Data	No Data	No Data	N/A	N/A
HDPE	50% PP	0.59% MC	No Data	No Data	No Data	No Data	No Data	No Data	N/A	N/A
HDPE	70% PP	0.59% MC	1	0.021	0.003	12.13		0.00	N/A	N/A
HDPE	70% PP	0.59% MC	2	0.017	0.002	9.37	No Measurement	No Measurement	N/A	N/A
HDPE	30% PP	0.93% MC	1	0.026	0.003	10.90	0.00	0.00	N/A	N/A
HDPE	30% PP	0.93% MC	2	0.025	0.005	18.47	No Measurement	No Measurement	N/A	N/A
HDPE	50% PP	0.93% MC	1	0.026	0.003	11.86	0.00	0.00	N/A	N/A
HDPE	50% PP	0.93% MC	2	0.025	0.006	22.06	No Measurement	No Measurement	N/A	N/A
HDPE	70% PP	0.93% MC	1	0.028	0.003	11.85	0.00	0.00	N/A	N/A
HDPE	70% PP	0.93% MC	2	0.022	0.005	23.90	No Measurement	No Measurement	N/A	N/A
HDPE	30% PP	1.13% MC	1	0.032	0.007	22.18	0.00	0.00	N/A	N/A
HDPE	30% PP	1.13% MC	2	0.031	0.009	30.65	No Measurement	No Measurement	N/A	N/A
HDPE	50% PP	1.13% MC	1	0.031	0.007	21.40	0.00	0.00	N/A	N/A
HDPE	50% PP	1.13% MC	2	0.041	0.014	33.83	No Measurement	No Measurement	N/A	N/A
HDPE	70% PP	1.13% MC	1	0.032	0.008	24.06	0.00	0.00	N/A	N/A
HDPE	70% PP	1.13% MC	2	0.031	0.010	31.49	No Measurement	No Measurement	N/A	N/A



Polymer	Blend%	MC%	Sample #	Total Area	Void Area	Void %	Molded Part Void Area	Molded Part Void %	ESR Area	ESR %
HDPE	30% PP	1.27% MC	1	0.028	0.004	13.77	0.00	0.00	N/A	N/A
HDPE	30% PP	1.27% MC	2	0.030	0.003	9.56	No Measurement	No Measurement	N/A	N/A
HDPE	50% PP	1.27% MC	1	0.031	0.011	36.52	0.00	0.00	N/A	N/A
HDPE	50% PP	1.27% MC	2	0.028	0.005	19.12	No Measurement	No Measurement	N/A	N/A
HDPE	70% PP	1.27% MC	1	0.022	0.001	5.37	6911.76	2.48	N/A	N/A
HDPE	70% PP	1.27% MC	2	0.029	0.003	9.98	No Measurement	No Measurement	N/A	N/A
HDPE	30% PP	1.37% MC	1	0.029	0.012	40.02	0.00	0.00	N/A	N/A
HDPE	30% PP	1.37% MC	2	0.031	0.011	37.09	No Measurement	No Measurement	N/A	N/A
HDPE	50% PP	1.37% MC	1	0.034	0.011	31.85	0.00	0.00	N/A	N/A
HDPE	50% PP	1.37% MC	2	0.030	0.002	7.80	No Measurement	No Measurement	N/A	N/A
HDPE	70% PP	1.37% MC	1	0.034	0.014	41.57	0.00	0.00	N/A	N/A
HDPE	70% PP	1.37% MC	2	0.031	0.014	46.41	No Measurement	No Measurement	N/A	N/A
ESR	Unblended	0.43% MC	1	0.021	0.004	19.12	15371.22	5.52	N/A	N/A
ESR	Unblended	0.43% MC	2	0.022	0.003	14.37	No Measurement	No Measurement	N/A	N/A
ESR	Unblended	0.85% MC	1	0.021	0.006	29.02	3929.29	1.41	N/A	N/A
ESR	Unblended	0.85% MC	2	0.020	0.005	26.59	11901.39	4.28	N/A	N/A
ESR	Unblended	1.09% MC	1	0.031	0.013	41.44	10261.67	3.69	N/A	N/A
ESR	Unblended	1.09% MC	2	0.031	0.010	33.32	No Measurement	No Measurement	N/A	N/A
ESR	Unblended	1.25% MC	1	0.028	0.008	27.14	17143.93	6.160832377	N/A	N/A
ESR	Unblended	1.25% MC	2	0.032	0.015	47.94	0.00	0.00	N/A	N/A
ESR	Unblended	1.40% MC	1	0.027	0.009	34.08	9084.91	3.26	N/A	N/A
ESR	Unblended	1.40% MC	2	0.024	0.012	49.24	14222.65	5.11	N/A	N/A
HDPE	Unblended	N/A	1	0.035	0.003	8.87	0	0	N/A	N/A
HDPE	Unblended	N/A	2	0.034	0.003	9.68	No Measurement	No Measurement	N/A	N/A
PP	Unblended	N/A	1	0.027	0.000	0.00	2785.95	1.001157317	N/A	N/A
PP	Unblended	N/A	2	0.028	0.000	1.66	No Measurement	No Measurement	N/A	N/A

APPENDIX F: MSDS AND TECHNICAL DATA SHEETS FOR ESR RESIN (25% GLYCEROL)



MSDS for BiologiQ GS250 Polymer Resin

1. Chemical Product Information

Product Name	BiologiQ GS250
Common Name	BiologiQ Starch Polymer Resin
Manufacturer	BiologiQ Inc. *Headquarters* 2400 E 25th St. Idaho Falls, ID 83404 *Manufacturing* 835 NE Main St. Blackfoot, ID 83221
Emergency Number	1-208-881-2648

2. Composition/Information on Ingredients

Chemical Name	Starch
CAS No: 9005-84-9	Non-Hazardous
Chemical Name	Glycerin
CAS No: 56-81-5	Non-Hazardous

3. Hazard Identification

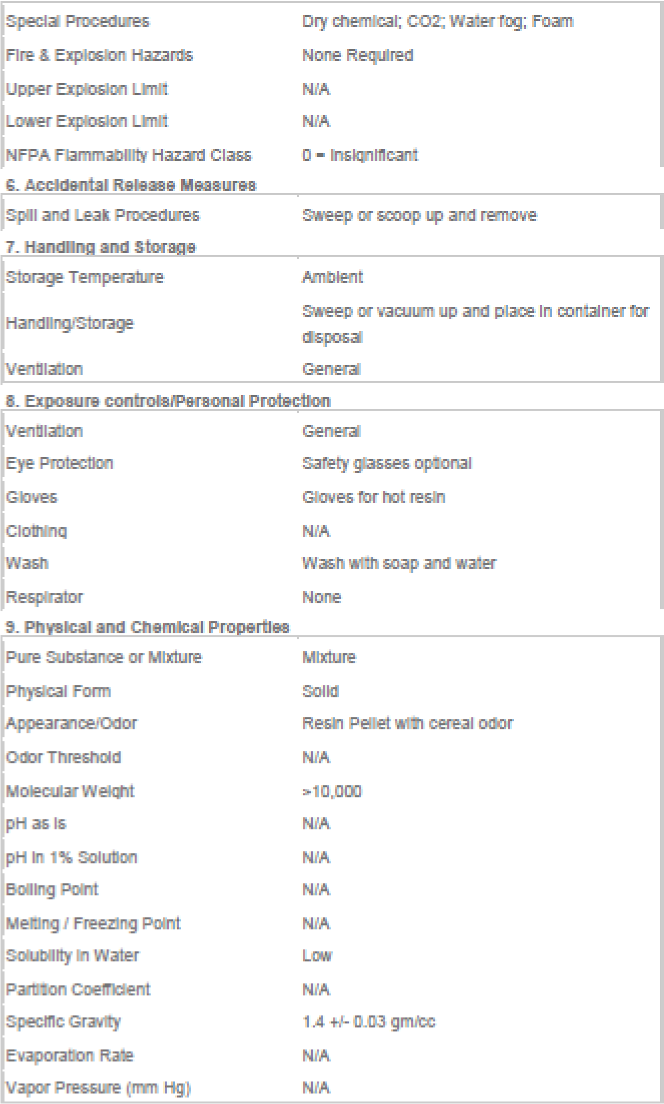
Eye	Particles may cause mechanical irritation.
Skin Contact	Low order of toxicity.
Inhalation	Low order of toxicity.
Ingestion	No hazard in normal industrial use.

4. First-Aid Measures

Eye	Flush eyes with large amounts of water until irritation stops
Skin Contact	Wash with soap and water.
Inhalation	Remove to fresh air.
Ingestion	N/A

5. Firefighting Measures

Auto Ignition	N/A
Flash Point	N/A



Special Procedures	Dry chemical; CO2; Water fog; Foam
Fire & Explosion Hazards	None Required
Upper Explosion Limit	N/A
Lower Explosion Limit	N/A
NFPA Flammability Hazard Class	0 = Insignificant
6. Accidental Release Measures	
Spill and Leak Procedures	Sweep or scoop up and remove
7. Handling and Storage	
Storage Temperature	Ambient
Handling/Storage	Sweep or vacuum up and place in container for disposal
Ventilation	General
8. Exposure controls/Personal Protection	
Ventilation	General
Eye Protection	Safety glasses optional
Gloves	Gloves for hot resin
Clothing	N/A
Wash	Wash with soap and water
Respirator	None
9. Physical and Chemical Properties	
Pure Substance or Mixture	Mixture
Physical Form	Solid
Appearance/Odor	Resin Pellet with cereal odor
Odor Threshold	N/A
Molecular Weight	>10,000
pH as is	N/A
pH in 1% Solution	N/A
Boiling Point	N/A
Melting / Freezing Point	N/A
Solubility in Water	Low
Partition Coefficient	N/A
Specific Gravity	1.4 +/- 0.03 gm/cc
Evaporation Rate	N/A
Vapor Pressure (mm Hg)	N/A

Vapor Density	N/A
Volatiles	None
Volatile Organic Compounds	N/A
Auto Ignition	N/A
Flash Point	N/A
Oxidizing Properties	N/A

10. Stability and Reactivity

Stability	Stable
Materials to Avoid	None
NFPA Reactivity Hazard Class	0 = Insignificant
	This product does not undergo spontaneous decomposition.
Hazardous Decomposition Products	Typical combustion products are CO, CO2, C, N, H20

11. Toxicological Information

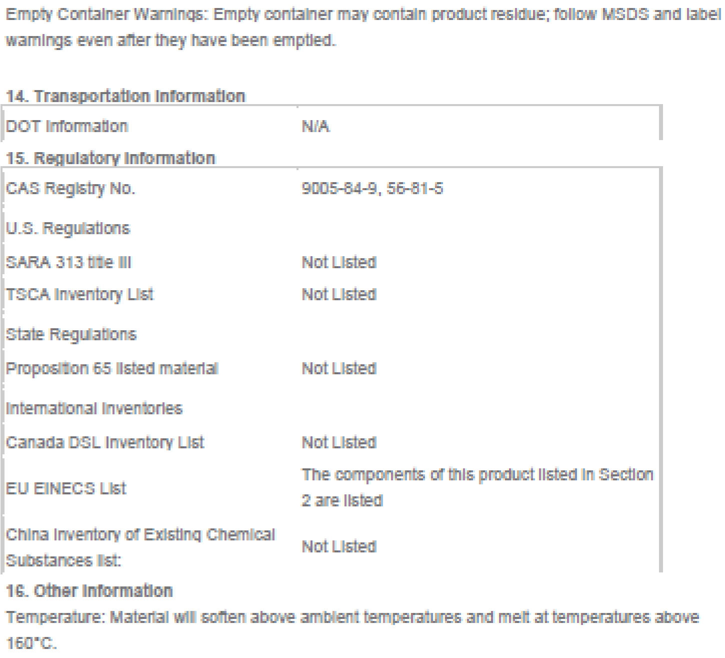
Product Toxicology	
Oral Toxicity	Low order of toxicity
Dermal Toxicity	Non-hazardous
Inhalation Toxicity	Non-hazardous
Eye Irritation	Non-hazardous
Chronic (Long-Term) Effects of Exposure	
Route of Entry	Eye, skin, inhalation, ingestion
Effects of chronic exposure	None
Target Organs	N/A
Special Health Effects	None known

12. Ecological Information

Biodegradability	Biodegradable in compost Testing per ASTM D6400 being performed
Incineratability	Incineratable
Toxic Volatiles	None expected with complete combustion

13. Disposal Considerations

Waste Disposal Methods: In accordance with existing federal, state, and local environment regulations



Empty Container Warnings: Empty container may contain product residue; follow MSDS and label warnings even after they have been emptied.

14. Transportation Information

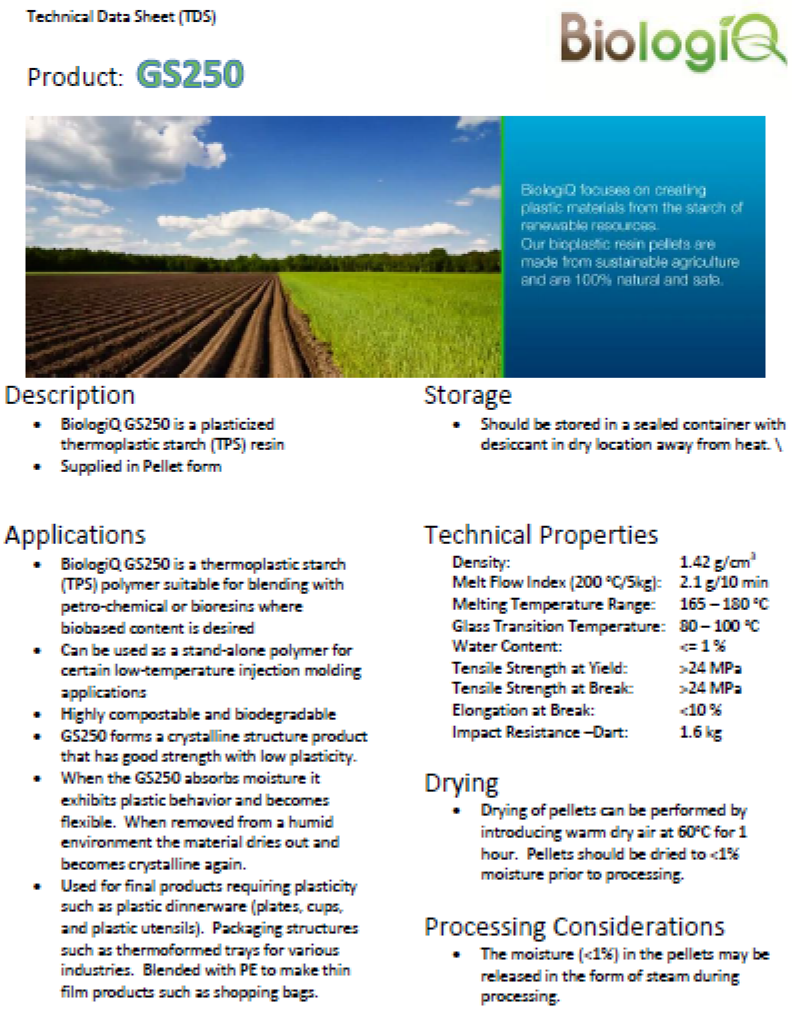
DOT Information	N/A

15. Regulatory Information

CAS Registry No.	9005-84-9, 56-81-5
U.S. Regulations	
SARA 313 title III	Not Listed
TSCA Inventory List	Not Listed
State Regulations	
Proposition 65 listed material	Not Listed
International Inventories	
Canada DSL Inventory List	Not Listed
EU EINECS List	The components of this product listed in Section 2 are listed
China Inventory of Existing Chemical Substances list:	Not Listed

16. Other Information

Temperature: Material will soften above ambient temperatures and melt at temperatures above 160°C.



Technical Data Sheet (TDS)

Product: **GS250**

BiologiQ

BiologiQ focuses on creating plastic materials from the starch of renewable resources.
Our bioplastic resin pellets are made from sustainable agriculture and are 100% natural and safe.

Description

- BiologiQ GS250 is a plasticized thermoplastic starch (TPS) resin
- Supplied in Pellet form

Applications

- BiologiQ GS250 is a thermoplastic starch (TPS) polymer suitable for blending with petro-chemical or bioresins where biobased content is desired
- Can be used as a stand-alone polymer for certain low-temperature injection molding applications
- Highly compostable and biodegradable
- GS250 forms a crystalline structure product that has good strength with low plasticity.
- When the GS250 absorbs moisture it exhibits plastic behavior and becomes flexible. When removed from a humid environment the material dries out and becomes crystalline again.
- Used for final products requiring plasticity such as plastic dinnerware (plates, cups, and plastic utensils). Packaging structures such as thermoformed trays for various industries. Blended with PE to make thin film products such as shopping bags.

Storage

- Should be stored in a sealed container with desiccant in dry location away from heat. \

Technical Properties

Density:	1.42 g/cm^3
Melt Flow Index (200 °C/5kg):	2.1 g/10 min
Melting Temperature Range:	165 – 180 °C
Glass Transition Temperature:	80 – 100 °C
Water Content:	<= 1 %
Tensile Strength at Yield:	>24 MPa
Tensile Strength at Break:	>24 MPa
Elongation at Break:	<10 %
Impact Resistance –Dart:	1.6 kg

Drying

- Drying of pellets can be performed by introducing warm dry air at 60°C for 1 hour. Pellets should be dried to <1% moisture prior to processing.

Processing Considerations

- The moisture (<1%) in the pellets may be released in the form of steam during processing.