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WOOD FIBER/HIGH DENSITY POLYETHYLENE COMPOSITES: ABILITY OF ADDITIVES TO ENHANCE MECHANICAL PROPERTIES

By

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ABSTRACT

WOOD FIBER/HIGH DENSITY POLYETHYLENE COMPOSITES: ABILITY OF ADDITIVES TO ENHANCE MECHANICAL PROPERTIES

BY

JOANNA DENISE CHILDRESS

Improvement of mechanical properties, for a composite of Aspen Hardwood fibers and recycled High Density Polyethylene (HDPE), can be achieved by the inclusion of additives. The four additives investigated in this study were: Ionomer Modified Polyethylene (Surlyn), Maleic Anhydride Modified Polypropylene (MAPP), and two Low Molecular Weight Polypropylenes (Proflow 1000 and Proflow 3000). Each additive was combined with recycled HDPE and Aspen Hardwood fibers in a twin-screw extruder to form the composite, and then compression molded. Creep, water sorption, tensile properties and impact strength were evaluated following ASTM standard procedures. All composites were approximately 40% by weight Aspen hardwood fibers. The effects of Surlyn and MAPP were studied at 1%, 3%, and 5% weight ratios. The effects of Proflow 1000 and Proflow 3000 were studied utilizing 5% additive. The inclusion of MAPP in the composite improved its mechanical properties overall. Addition of Surlyn produced some positive effects but not at a statistically significant level. The inclusion of Proflow 1000 and Proflow 3000 generally decreased the mechanical properties of the composites.

to my mother and my son Lon, for inspiring me to reach for the stars and being there if I fell short

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The solid waste disposal system has created a crisis. It was estimated in 1988 that nearly 25% of the major cities in the U.S., will run out of waste disposal capacity by 1993 (Thompson and Bluestone, 1987). The growth of the plastics industry has naturally increased the amount of plastics in the solid waste disposal system. In 1986, the 11.5 billion pounds of plastics used in packaging consisted of the following: LDPE and LLDPE 33%, HDPE 31%, PS 11%, PP 9%, PET 7%, PVC 5%, others 4% (Modern Plastics, 1987). These plastics were used in the following industrial, institutional and consumer packaging applications: films 35%, bottles 27%, containers 24%, coatings 9%, and closures 5% (Modern Plastics, 1987).

The increasing presence of plastics in the solid waste disposal system has also increased public resistance to them. In 1987, there were several bills introduced in legislatures across the United States, due to increased concern regarding plastics packaging disposal. The possible ban of polyvinyl chloride packaging was introduced in the Vermont legislature. A bill prohibiting the sale of expanded polystyrene products was also introduced in the Connecticut legislature. A great deal of discussion regarding regulating the plastics packaging industry has been focusing on requiring that plastics used for packaging be degradable. In 1987 there was a proposal in the

U.S. Congress to ban non-biodegradable six-pack beverage container bundling devices and there are also activities at State levels to ban non-biodegradable fast-food packaging.

Plastics are not inherently degradable and their permanence is one of their greatest assets. Some advances have been made regarding degradable plastics, but these can in no way compete with the growth of the plastics industry. In just the past 10 years the U.S. plastic resin industry has grown by 70% (Resource Integration Systems Ltd., 1987). This growth has been particularly strong in the areas of packaging, construction and transportation. By the year 2000 it is predicted that plastic packaging material will grow from 25% of the total packaging market share to 50% (Resource Integration Systems Ltd., 1987). An increase of over 3 1/2 times 1982 levels, is expected in the nations post-consumer plastic waste from construction (Resource Integration Systems Ltd., 1987). In regards to transportation, one industry source predicted that by 1992, the typical U.S. car will contain more than 400 lbs. of plastics and components (Resource Integration Systems Ltd., 1987).

Government and industry alike have been seeking alternative methods of disposal, that will deal with the problem of plastics in the solid waste stream in a timely manner. One method that would reduce the amount of plastics in the solid

waste disposal system is recycling. In the past, polyethylene terephthalate (PET) was one of the few plastics that was actively sought for recycling. High density polyethylene (HDPE) generates a significantly greater amount of tonnage yearly than PET, therefore both are now being actively sought and recycled. HDPE is readily identified by consumers in the form of plastic milk jugs. In the State of Michigan, for example, over 12,000 tons of plastic milk jugs are discarded each year (Resource Integration Systems Ltd., 1987). HDPE is also used as packaging for household chemicals, bleach, detergent, and cosmetics. Barriers to the recovery of HDPE include contamination and health concerns. Recycled plastics are generally considered unsuitable for direct food contact, due to fear of contaminants.

An advantage in recovering HDPE is that it is relatively easy to recycle compared with many other plastics. Products manufactured from recycled HDPE include: signs, toys, basecups for soft drink bottles, traffic barrier cones, pipe, and trash cans. Although recycled HDPE is manufactured into many different items, this investigation was concerned with using it as a low cost matrix for structural polymer composites. Recycled HDPE from milk bottles was chosen as a matrix material in this investigation because of its low cost, abundance, ability to be easily identified and recycled, and because it is not considered suitable for direct food contact

applications. Also, previous studies indicate that recycled HDPE milk bottles have nearly the same mechanical properties as virgin resins (Yam, et al, 1988). HDPE by itself is limited in its use for structural applications, due to its low stiffness and high creep. But if it is reinforced with a stiff and strong filler, these limitations may be overcome. The filler being investigated in this study is Aspen Hardwood Fibers. Advantages of wood fiber include its low density, abundance, high strength-to-weight ratio, and low cost.

Prior studies investigating the mechanical properties of wood fiber/HDPE composites have shown very little improvement over unreinforced HDPE (Kalyankar, 1989). This is not surprising since wood fibers are polar and hydrophilic, while HDPE is nonpolar and hydrophobic. The role of the matrix material is to bind the fibers and protect them. Although some bonding may occur purely by the mechanical interlocking of two surfaces, this bonding is not strong enough to prevent the composite from having poor mechanical properties. In the absence of a strong bond between the matrix and fibers, the two may separate. This type of failure is known as debonding.

Prior research has shown that the inclusion of some additives will enhance mechanical properties (Nieman, 1989 and Keal, 1990). Better dispersion of the fibers in the matrix will aid in "wetting" of the fibers. This will allow the fibers to be

totally enclosed by the matrix, which could possibly enhance mechanical properties. For this reason materials that are known dispersants will be considered as possible additives. Prior research has also shown that coupling agents are able to act as a bridge between the filler and matrix. Microscopy has revealed, by implication, that no more than the equivalent of a monolayer of coupling agent on appropriate surfaces is sufficient to promote good bonding (Sterman and Bradley, 1961).

The effects of the inclusion of additives on a composite of Aspen Hardwood fibers and recycled HDPE were investigated in this study. The four additives investigated were: Ionomer Modified Polyethylene (Surlyn), Maleic Anhydride Modified Polypropylene (MAPP), and two Low Molecular Weight Polypropylenes (Proflow 1000 and Proflow 3000). The effects of Surlyn and MAPP were studied at 1%, 3% and 5% weight ratios. Prior research incorporating Surlyn and MAPP as additives in a HDPE/Wood Fiber composite, showed potential for improving the adhesion between the wood fibers and the HDPE (Nieman, 1989 and Keal, 1990). Part of this study involved continuing to investigate these findings. It is believed that Proflow 1000 and Proflow 3000 provide better dispersion of the fibers, due to decreasing the viscosity of the mix. The effects of these additives were studied utilizing 5% additive because this was a preliminary screening study only.

LITERATURE REVIEW

LITERATURE REVIEW

Composite Materials

Introduction

Since the development of civilization, there have been records of composite materials. In order to diminish shrinkage during the drying and shattering in the firing process, crushed rock and organic materials were mixed with pottery clay, as early as 5000 B.C.. The history of polymer based composites is recorded in the books of Genesis and Exodus in the Bible and can be traced to the Babylonians around 4000 - 2000 B.C. (Richardson, 1977). River boats were constructed at this time in Egypt and Mesopotamia using bundles of papyrus reed embedded in a matrix of bitumen. The origins of complex materials can be traced to ancient times and are a very vital part of civilization today.

Finding a definitive definition of a composite material is a very difficult process and has become a very controversial area of debate. There is an agreement among most sources that in order for a material to be considered a composite, it must be combined in such a way that it produces a material with a more complex structure, but the constituents substantially retain their uniqueness (Richardson, 1977). In addition, materials can be considered a composite if they are composed of: 1)one matrix (or continuous phase) and one or more

disperse phases or 2) two or more continuous phases and one more dispersed phase in each continuous phase.

Virtually every known commercially produced thermoset has been used as a matrix and embedded with reinforcing agents or fillers, at an experimental stage. Thermosets such as cross-linked polyester resins, expoxides, phenolformaldehyde resins, silicones, and melamine-formaldehyde resins are among the most commonly used as matrix materials. Silicones are used for electrical and aerospace applications. Polyesters are used to make corrugated sheeting, boats, tanks, and piping, to name a few of its applications. Polyesters are often chosen as a continuous phase because reinforcing agents can be easily incorporated within the matrix.

As with thermosets, virtually every known commercially produced thermoplastic could or has been utilized as a matrix material. Thermoplastics are generally considered to have poor mechanical properties compared to mild steel. Therefore various studies have been conducted to try and improve its mechanical properties, by incorporating reinforcing agents and fillers. For example, by incorporating 20 - 40% glass fibers into a nylon 66 matrix, properties such as modulus, tensile strength, hardness, and creep resistance are increased substantially (Brydson, 1975). The type of filler used as a reinforcement is very important, since the final properties of

the composite are naturally controlled by the properties and quantities of the component materials. The filler should provide maximum improvement of desired physical properties, be inexpensive and readily available, have good dispersion and wetting characteristics, and be available in controlled particle sizes, among other desired requirements.

Interface and Interphase Regions

"Within any composite material there must be at least two discernible component phases which inevitably, by definition, must be separated by an interface and interphase region" (Richardson, 1977). The interface and interphase regions greatly influence the properties of the final composite material. Mechanical strength can only be achieved by the uniform efficient transfer of stress between matrix and fibers, via a strong interfacial bond. The strength of the interfacial bond is also responsible for promoting good environmental performance even when the composite is loaded. As stated earlier, the role of the matrix is to bind the fibers together and protect them from environmental conditions. With these factors in mind, many fibers and reinforcing agents are pre-treated before they are incorporated into a composite. A common pretreatment uses a coupling agent that acts as a bridge between the filler and the matrix, thus creating a stronger bond between the two. Research has shown that very small additions of a coupling

agent are sufficient to promote good bonding and improve mechanical properties.

Also, it is believed that it is essential to have good "wetting" of the fibers in order to increase adhesion and produce a strong composite. With increased dispersion, the fibers will be "wetted out" or totally enclosed by the matrix. Absorption alone can produce increased adhesion between the fibers and matrix. But, upon examining the surface wettability of a composite, it shows that improved surface wettability can be thought of as a secondary concern in improving fiber/matrix bonding.

When producing a composite material it is very difficult to simultaneously improve properties such as stiffness, mechanical strength, and toughness. In order to achieve mechanical strength you must obtain uniform transfer of stress between matrix and fibers while producing a strong bond at the interface. An entire field of research has been devoted to understanding the mechanisms involved in resolving the tensile strength/toughness dilemma. This can be explained in part by the behavior and character of the interface. Controlled debonding at the interface has been shown to promote tensile strength while impairing toughness, in glass fiber/polyester laminates (Richardson, 1977). Good adhesion between filler and plastic is desirable because it improves strength, but

unfortunately it increases the tendency to brittle failure and makes the material more notch sensitive (Richardson, 1977). In addition, impact behavior can be explained by considering the reinforcement of brittle matrices and ductile matrices. In the case of ductile matrices (e.g., polyethylene), the triaxial restraint of the matrix between fibers limits the elongation of the matrix, and thus addition of rigid fibers greatly reduces the toughness (Agarwal and Broutman, 1980). On the other hand, addition of fibers to a brittle matrix (e.g., polystyrene) can increase toughness because of crack blunting, branching, and arrest effects (Agarwal and Broutman, 1980). Although the interfacial condition significantly influences the mechanical behavior of a composite material, it is only one of several factors involved.

Prediction of Properties

One of the most important factors determining the properties of composites is the relative proportions of the matrix and reinforcing material (Agarwal and Broutman, 1980). The properties of these constituents, their distribution and physical and chemical interactions, will be the most important parameters controlling mechanical properties. The relative proportions are commonly given as weight fractions or volume fractions. Definitions of the volume fractions and weight fractions are as follows (throughout, the subscripts c, f, and m are consistently used to represent the composite material,

fibers, and matrix material, respectively): (Agarwal and Broutman, 1980)

$$V_f = \frac{v_f}{v_c} \quad ; \quad V_m = \frac{v_m}{v_c} \qquad \text{where } v_c = v_f + v_m \quad (1)$$

$$W_f = \frac{w_f}{w_c} \quad ; \quad W_m = \frac{w_m}{w_c} \qquad \text{where } w_c = w_f + w_m \quad (2)$$

By incorporating density in the equations, an equation relating volume fractions and weight fractions can be derived: (Agarwal and Broutman, 1980)

$$W_i = \frac{\rho_i}{\rho_c} V_i \quad (3) \quad ; \quad V_i = \frac{\rho_c}{\rho_i} W_i \quad (4)$$

where: ρ is equal to density

Due to voids in the composite, density calculated theoretically from weight fractions may not always be equivalent to the experimentally determined density. The difference in densities will be the void content and the volume fraction of voids can be calculated by: (Agarwal and Broutman, 1980)

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \qquad (5)$$

where: ρ_{ct} = theoretically determined density

ρ_{ce} = experimentally determined density

V_v = volume fraction of voids

Although the properties of a composite can be determined by experimental methods, it may not be cost effective to do so and the process may be time consuming. Mathematical models for studying properties such as tensile strength and modulus of elasticity have been developed and are quite accurate. These models can help in deciding whether or not to proceed with fabrication of the composite. The stress at a given strain can be calculated thus: (Agarwal and Broutman, 1980)

$$\sigma_c = \sigma_f V_f + \sigma_m V_m \qquad (6)$$

and the elastic modulus can be calculated as follows: (Agarwal and Broutman, 1980)

$$E_c = E_f V_f + E_m V_m \qquad (7)$$

The equations represent a relationship known as the rule of mixtures, which implies that the contributions of the fibers and the matrix to the composite properties are proportional to their volume fractions. As stated earlier, the composite properties are greatly influenced by the concentration of its constituents. When defining short-fiber composites, mathematical models that are based on continuous fiber composites and/or composites where the fiber length is significantly greater than the length of stress transfer, have to incorporate corrections in stress or volume fraction of the fibers, V_f,.

Composites that are embedded with short fibers are often called discontinuous fiber reinforced composites. In short fiber composites the fibers are loaded indirectly and the strength of the matrix and the interfacial bond determine the mechanical properties. The mechanical properties of the composite will only be maximized if the fibers are parallel to the loading direction and if the fibers are uniform in their strength values. Also, the transfer of stress from matrix to fibers will be less efficient with misoriented fibers.

Internal material failure may be caused by a)microcracking of

the matrix, b)breaking of the fibers, and c)separation of fibers from the matrix or debonding. Microcracking of the matrix starts with a buildup of stress concentrations at the fiber ends. This buildup can cause the fiber ends to become separated from the matrix at very small loads and produce a microcrack in the matrix. If the microcrack propagates parallel or in a direction normal to the fibers, it could lead to complete composite failure. The bond between the matrix and the fibers at the interface is an important factor, since the interface is responsible for transmitting the load from the matrix to the fibers. The mode of propagation of microcracks will be controlled by the interface. If there is a strong bond between the matrix and fibers, the interface may prevent the propagation of microcracks along the fiber lengths.

A cohesive failure can occur, which involves breaking of the fibers. Separation of the two phases can also occur, which is referred to as debonding. This is an adhesive failure. The bond strength is an important measurement in determining the type of failure. Due to the inherent problems with preparing wood fiber samples, and the high degree of precision required for testing the bond strength, satisfactory test methods for bond strength are not available. Fortunately, bond strength can be determined by performing tests with single fibers. This test can generate data on shear strength of the

interfacial bond. The relationship between compressive stress and shear stress is as follows: (Hull, 1981)

$$\tau_s \approx 2.5\sigma_c \qquad (8)$$

where: σ_c = compressive stress

τ_s = shear stress

In order to determine the shear strength of the interface, applied compressive stress at which debonding is initially detected, can be obtained experimentally. Also, by using the following formula a value for tensile strength of the interface can be determined: (Hull, 1981)

$$\sigma_\perp = \frac{\sigma_c(\nu_m - \nu_f) E_f}{(1+\nu_f-2\nu_f^2) E_m} \qquad (9)$$

where: $\sigma_\perp$ = stress perpendicular to the fibers

σ_c = net section compressive stress (load divided by minimum area)

ν_m = Poisson's ratio of the matrix

ν_f = Poisson's ratio of the fiber

E = Young's modulus

During fabrication the composite will also undergo stresses caused by the fabrication process. The fabrication temperature and the difference in the thermal expansion of the constituents can cause these stresses (Agarwal and Broutman, 1980). They are known as residual stresses and can aid in the failure of the composite.

The strength of a composite is greatly influenced by the lengths of the fibers. A long fiber has a greater chance of having a section that is weak and therefore long fibers are not very strong. As discussed earlier, loads are not applied directly to the fibers, but are transferred by the matrix to the fibers through the fiber ends and also through the cylindrical surface of the fibers. The end effects can be neglected when the fiber length is significantly greater than the length over which the transfer takes place. But, when dealing with short-fiber composites the effects of the fiber ends become extremely important. Analyzing the stress transfer for short-fiber composites is done by considering the equilibrium of a small element of fiber such that: (Agarwal and Broutman, 1980)

$$(\pi r^2)\sigma_f + (2\pi r dz)\tau = (\pi r^2)(\sigma_f + d\sigma_f) \qquad (10)$$

which equals: $$\frac{d\sigma_f}{dz} = \frac{2\tau}{r}$$

where: r = fiber radius

τ = shear stress on the cylindrical fiber matrix interface

dz = infinitesimal fiber length

This equation implies that the fiber stress increases at a rate proportional to the shear stress at the interface, for a fiber of uniform radius. Therefore by integrating the equation, fiber stress at cross-sectional distance z from the fiber end can be determined as follows: (Agarwal and Broutman, 1980)

$$\sigma_f = \sigma_{f_o} + \frac{2}{r}\int_0^z \tau dz \qquad (11)$$

where: σ_{f_o} = stress on fiber ends

The maximum fiber stress, which occurs at midfiber length for short fibers can be calculated as follows: (Agarwal and Broutman, 1980)

$$(\sigma_f)\max = \frac{\tau_y l}{r} \qquad (12)$$

where: $(\sigma_f)\max$ = the maximum fiber stress

τ_y = the matrix yield stress in shear

r = the fiber radius

l = the fiber length

The load transfer length (l_t), which is the smallest length the fiber can be in order for the maximum fiber stress to occur, is given as: (Agarwal and Broutman, 1980)

$$\frac{l_\tau}{d} = \frac{(\sigma_f)\max}{2\tau_y} \qquad (13)$$

where d (=2r) which is the fiber diameter. The critical fiber length, l_c, is the smallest acceptable fiber length in which the maximum allowable fiber stress can occur and is given as: (Agarwal and Broutman, 1980)

$$\frac{l_c}{d} = \frac{\sigma_{fu}}{2\tau_\gamma} \qquad (14)$$

where: σ_{fu} = maximum allowable fiber stress

The load-transfer length and critical fiber length are often referred to as the ineffective length. These lengths are termed as ineffective because it is over these lengths that the fiber can support stresses up to the maximum fiber stress. In a short-fiber composite the fiber ends lower the elastic modulus and strength. The fiber modulus must be greater than the matrix modulus in order to obtain high stresses in the fibers.

Prior Research

Within this decade composites will become a dominant segment of the plastics industry. The competition in high-volume markets for moderately priced products is encouraging a search for composites that can offer a new balance of product quality, performance, and cost. The following is a review of selected prior research in this area.

Nieman (1989) studied the effects of the inclusion of additives in HDPE/wood fiber composites. The five additives investigated were: Low Density Polyethylene (LDPE), Stearic Acid, Chlorinated Polyethylene, Maleic Anhydride Modified Polypropylene (MAPP), and Ionomer Modified Polyethylene (Surlyn). The mechanical properties evaluated were tensile properties, impact strength, water sorption, and creep. The specimens were also analyzed using scanning electron microscopy (SEM). Enhancement of tensile properties, creep, and water sorption were achieved with the inclusion of MAPP, while the inclusion of LDPE and Stearic acid were determined ineffective. Surlyn displayed positive results in tensile properties, creep, and water sorption, while the chlorinated polyethylene showed little effect either way. These results indicate that there may be an increase in interfacial bonding due to the inclusion of MAPP and Surlyn.

Keal (1990) studied the effects of dual additive systems on

the mechanical properties of Aspen hardwood fiber/recycled HDPE composites. The additives investigated were Stearic Acid, Maleic Anhydride Modified Polypropylene, Stearic Acid, and Ionomer Modified Polyethylene. The mechanical properties evaluated were impact strength, tensile properties, and creep. Improvement in tensile strength and creep was observed for all additives studied. Improvement in impact strength was only noted in the Stearic acid/Ionomer Modified Polyethylene additive system. Although the dual additive systems showed improvement in some mechanical properties, they offered no significant improvement over using single additives.

Raj et al (1988) studied the effects of various isocyanates as bonding agents for composites of aspen wood fibers and linear low density (LLDPE) and high density (HDPE) polyethylenes. Three procedures were employed to coat the aspen fibers in a roll mill. Procedure 1 involved mixing aspen fibers (15.0g), isocyanate (1.35g), polymer (HDPE or LLDPE, 4.5g), and maleated propylene wax (2.0g). Procedure 2 involved mixing aspen fibers (15.0g), maleic anhydride (1.0g), polymer (HDPE or LLDPE, 4.5g), and an initiator di-t butyl peroxide (0.3g). Procedure 3 involved mixing aspen fibers (15.0g), maleic anhydride (4.5g), di-t butyl peroxide (0.8g), and polymer (HDPE or LLDPE, 4.5g). The following isocyanates were used as bonding agents: 1) Polymethylene (polyphenyl isocyanate), 2) Tolene -2-4-diisocyanate, 3) 1-6 Hexamethylene diisocyanate,

and 4) Ethyl isocyanate. The bonding agents improved the tensile properties of the composites. In regards to the two polymers, HDPE performed better than the LLDPE composites. Also, higher tensile strength and tensile modulus was noted in the HDPE composite with short fibers as the reinforcement. The effectiveness of wood fibers in terms of cost and performance was demonstrated with the comparison of composites of HDPE with aspen fibers, mica, and glass fibers.

Patfoort and Bucquoye (1981) studied the effect of fiber length, fiber content, fiber coating content, number of plies, palm-glass fiber combinations, three different types of polymeric fiber coatings, and selected formulations of a polyester resin on a composite material based on palm fibers. Palm fibers were found to be equal in their physical, chemical, and tensile properties to other very well known natural hard fibers. Even though the palm fibers were found to be inferior in tensile strength and modulus compared to glass fibers, reinforcing with glass was found to be twice as expensive in relation to its strength. When the fiber length exceeded 9 cm there was no significant improvement in tensile properties. When poly(vinyl alcohol) was used as the interfacial agent, it was shown that the tensile properties for the palm fiber composites, were directly proportional to the volumetric fiber concentration. Palm-glass fiber combinations increased the flexural strength and tensile

properties significantly. An increase in mechanical properties was noted for the poly(vinyl acetate) and poly(vinyl alcohol) coated composites, with poly(vinyl acetate) exhibiting the best. The 2-hydroxyethyl methacrylate coated fibers did not seem to improve the tensile and flexural properties. The strength/price ratio was found to be favorable to the natural fiber composites.

Owolabi et al (1985) investigated the mechanical properties of composites of coconut hair and thermosetting press materials. The reinforcing filler in this investigation was coconut fibers, imported in the form of coarse-fiber rope. The bonding agents investigated were a resole-type phenol-formaldehyde (PF) resin and a novolac-type PF resin. The composition of the resole-type PF composite (parts by weight) was approximately resole-type PF resin 40; chopped coconut fiber 58; MgO 1; Zn-stearate 1. The composition (parts by weight) of the novolac-type PF composite was approximately novolac-type PF resin 58; chopped coconut fiber 35; MgO 1; Zn-stearate 1; hexamethylene-tetramin 5. Unsaturated polyester was also used as a bonding agent and the materials were produced on the basis of the following (parts by weight): unsaturated polyester binder 100; $CaCo_3$ filler 75; MgO 3; styrene monomer 12; Zn-stearate 2.5; tert-butyl perbenzoate 1.25; and chopped fibrous reinforcement 100. The type and quantity as well as pretreatment of the chopped fibrous

reinforcement was changed from glass fibers to coconut fibers. The coconut fibers were pre-treated in some cases in order to achieve better coupling between the fibers and the polymer. The first method of pretreatment involved treating the fibers with a dilute NaOH solution at 100°C for 1.5 hrs. The second method involved preirradiating the coconut fibers and the third method was a combination of methods 1 & 2. As precondensation time increased, the compressive strength increased, the impact strength decreased and the flexural strength remained about the same for the PF (resole)-bound coconut fiber composite. Using NaOH as a pretreatment enhanced the mechanical properties of almost all the composites. A ratio of 58/42 between the matrix and fibers was found to be the optimum mix. For the novolac-type PF resin the only improvement was seen in the compressive strength of the composite. The composites using unsaturated polyester as the binding material produced some interesting results, in that there was not a significant decrease in tensile strength when the composites reinforcing filler was changed from glass fibers to coconut fibers. However, the tensile modulus and impact strength for the unsaturated polyester/coconut fiber composite was well below that of the unsaturated polyester/glass fiber composite. Also, even though the flexural strength decreased when glass fibers were changed to coconut fibers in the composite, the pre-treated coconut fibers increased the flexural strength significantly

compared to the composites with untreated coconut fibers. It was found that in glass-fiber reinforced UP press materials, a significant part of the glass filler can be changed to coconut fibers.

Adams (1988) evaluated the curing, rheology, water resistance, flame generation, smoke generation, and laminate physical properties of a composite of unsaturated polyester and several different brands of gypsum. The gypsum-filled systems were compared to a composite of fiberglass, alumina trihydrate (ATH) and calcium carbonate (CC). For the gypsum-filled systems with about the same exotherm temperatures, the gel times and gel-to-peak times were slightly faster. Exotherm temperatures decreased for all systems, as filler loading increased. The thixotropic indexes were higher for the gypsum-filled systems than for the ATH/CC systems and increased with filler loading in the gypsum systems, while remaining almost constant in the ATH/CC systems. All laminates exhibited excellent water resistance and physical-mechanical properties. Also, the flame spread of all samples was less than 200 and smoke generation was less than 600. The results indicate that the composites performance is maintained.

Maldas and Kokta (1989) evaluated under various aging conditions the mechanical properties and dimensional stability

of aspen hardwood fiber/polystyrene composites. The reinforcing filler was in the form of chemithermomechanical pulp. The aging conditions under which the composite was evaluated were: variations in the testing temperature, exposure to boiling water, and heating in an oven at +105°C. Poly[methylene(polyphenyl isocyanate)] was used as a coupling agent to overcome incompatibility of the two constituents. Other variables investigated were the influence of the coupling agent and treatments such as coating and grafting. The treated composites showed superior mechanical properties and better dimensional stability compared to the non-treated fiber-filled composites. Also, the mechanical properties and dimensional stability of the treated composites were better when compared to those studied at ambient conditions. It is believed that the treated composites showed greater resistance under the different aging conditions, due to an efficient and strong interfacial bond.

Jindal (1986) investigated the mechanical behavior of composites composed of bamboo fibers and Araldite (CIBA-CY 230). Tensile strength, tensile modulus and impact strength were measured. The bamboo fiber obtained for this study is known as Dendrocalamus Strictus and was procured from the market in a semi dried condition. The results obtained showed that the yield and ultimate tensile strengths of the composites increased with the increasing volume fraction of

fibers. The experimentally determined values for tensile strength were nearly twice the values determined theoretically. Although the impact tests showed that notching the samples had no effect on impact strength, the impact strength values obtained were poor. The composites' tensile strength was approximately equal to the tensile strength of mild steel, although the density of the composite is only 1/8 the density of mild steel. These results are very promising, showing that this material may eventually be useful in light weight structural applications.

Bataille et al (1990) studied the mechanical properties of composites of cellulose fibers and low density (LLDPE) and high density (HDPE) polyethylenes. Benzoyl peroxide (BPO) and dicumyl peroxide (DCP) were used as adhesion modifiers. The LLDPE matrix was LL-3030 from Esso Chemical Canada. The HDPE was supplied by Union Carbide and the cellulose fibers used were a highly bleached hardwood pulp from Sigma Chemical Co. The cellulose fibers were treated with a coupling agent using two methods. Method 1 involved depositing the coupling agent from methanol/water solution adjusted to Ph 3 with acetic acid. Method 2 involved mixing the cellulosic fibers with a silane/dichloromethane solution and evaporating the solvent. Two methods for application of the peroxides were also used. Method 1 (MS) involved treating the cellulosic fibers with a methanol solution containing BPO and then removing the

solvent. Method 2 (DM) involved adding the BPO and DCP to the polyethylene/cellulose mixture during processing. The addition of BPO lead to a significant increase in the yield strength compared to either the untreated material or the silane treated composites. Adding BPO using method 1 was not as effective as method 2. The yield strength of the LLDPE/cellulose composite increased by 70% while the composite with HDPE as a matrix increased by only 15%. These results were obtained when using BPO and mixing the components at 160°C. It was found that if DCP replaces BPO the yield strength maximizes at a lower concentration indicating that it may be more efficient. Also, yield strength for the cellulose/LLDPE system, pre-treated with silane, showed a relatively small improvement as compared to the effect of the peroxides addition.

Simpson (1991) evaluated mechanical properties of aspen hardwood fiber/recycled polypropylene (PP) composites versus aspen hardwood fiber/virgin PP composites. The recycled PP matrix material consisted of reground multi-layer ketchup bottles which were composed of: ethylene vinyl alcohol (EVAL Solarnol DC), adhesive (Mitsui Monoply MT38), and PP (Soltex 4104). The reinforcing filler consisted of aspen hardwood fibers in the form of thermomechanical pulp (TMP). Aspen fiber ratios of 30%, 40%, and 50% were incorporated in the matrix material. The effect of fiber orientation on the

mechanical properties was also evaluated. Optimum tensile strength was reached at 30% fiber loading. In regards to orientation, tensile strength was greatest in the lengthwise direction. The % elongation decreased as fiber loadings increased. Both composites exhibited an increase in impact strength and water sorption as fiber loadings increased. They also exhibited poor dimensional stability under extreme environmental conditions. The recycled PP/aspen fiber composite generally displayed better mechanical properties under normal and extreme environmental conditions.

EXPERIMENTAL

EXPERIMENTAL

Materials

High Density Polyethylene (HDPE) dairy bottles were supplied by Peninsular Products Co. The bottles were cut into quarters and granulated into resin using a Lowline Granulator Model 68-913, from Polymer Machinery Corp. HDPE is fabricated at 150°C and 30 atm with a catalyst. It has a regular structure, which means its' chains are almost completely linear. For every 200 main chains (carbon atoms) it has less than 1 side chain or branches. In general, a polymer must have a regular structure in order to be crystalline. HDPE is very crystalline, being between 65-90% crystalline. The crystallinity of a polymer affects its properties. Usually, crystalline materials are highly packed together and are very dense. The density of HDPE is between 0.94-0.965 g/cc. The advantages of highly crystalline materials are that they are stiffer, have high tensile strengths, and have low oxygen permeability. A disadvantage is that they tend to be brittle. HDPE has a melt temperature between 130-135°C and a glass transition temperature of -120°C. It is also hydrophobic and nonpolar in nature. The structure of HDPE can be found in Appendix D.

Aspen hardwood fibers were chosen as the reinforcing filler for this study. Four types of cells are present in most hardwood species: fibers, vessel segments, and axial and

transverse parenchyma. Fibers are polar in nature and hydrophilic. They are crystalline and the cell walls contain 40-60% cellulose and 20-30% lignin. They are thick-walled, elongated cells with closed pointed ends. The fibers were in the form of thermomechanical pulp (TMP). This mechanical pulping process is one in which the fibers retain primarily all of its lignin and natural waxes, because during the pulping process a minimum amount of damage occurs to the lignin or hemicellulose. The lignin and natural waxes in wood fibers can aid fiber dispersion in nonpolar hydrocarbon polymers (Simpson, 1991). Natural fibers are often chosen as fillers due to their low cost (approximately $ 0.10/lb including freight), availability, stiffness and strength. The load will be transferred from the HDPE matrix through the fiber ends and over the length of the fibers, which are typically 0.7-3 mm long (Nieman, 1989). The fibers are conditioned for at least 40 hr at 22°C and 50% RH before combining them with HDPE. The structure of the fibers can be found in Appendix D.

The four additives investigated in this study were: Ionomer Modified Polyethylene (Surlyn), Maleic Anhydride Modified Polypropylene (MAPP), and two low molecular weight polypropylenes (Proflow 1000 and Proflow 3000). Table 1 lists the additives and gives a brief description of each.

Table 1. List of Additives

Additives
1. Ionomer Modified Polyethylene (Surlyn 1605, Du Pont); Cost = $1.27/lb./truckload.
2. Maleic Anhydride Modified Polypropylene, MAPP (Hercoprime, Himont); Cost = $12.00/lb.
3. Low Molecular Weight Polypropylene (Proflow 1000, Polyvisions); Cost = $1.37/lb./truckload.
4. Low Molecular Weight Polypropylene (Proflow 3000, Polyvisions); Cost = $1.41/lb./truckload.

Ionomer modified polyethylene (Surlyn) was selected because of its polar nature. HDPE is nonpolar in nature and hydrophobic, while the wood fibers are polar and hydrophilic. The polar nature of Surlyn and its ionic bonds may assist in producing a strong interfacial bond. Surlyn is a thermoplastic material that is very tough, flexible, transparent, and will adhere to metals, polyolefins and nylons (Nieman, 1989). It also has excellent abrasion resistance and is very compatible with the filler. The structure of Surlyn can be found in Appendix D.

Maleic Anhydride Modified Polypropylene (MAPP) is a coupling agent. A coupling agent is commonly used as a pretreatment and is believed to act as a bridge between the filler and the matrix. Very small amounts of the coupling agent are said to produce significant improvements in mechanical properties.

Microscopy has revealed that only a monolayer of coupling agent is sufficient to improve the bond between the fiber and matrix (Sterman and Bradley, 1961). Coupling agents also tighten up the polymer structure at the interface while still being involved with chemical bonding with the fibers. Without a strong bond between the matrix and the fibers, the two can easily be separated. A strong interfacial bond is also very important in promoting good environmental performance and aiding in increasing transverse strengths. The structure of MAPP can be found in Appendix D.

Low Molecular Weight Polypropylenes (Proflow 1000 and Proflow 3000) have the properties associated with high molecular weight polypropylene resins, but differ in their melt flow properties. They rapidly transform to low melt viscosity at their melting points, which allows them to be readily dispersed into other plastics. It was hypothesized that the Proflow resins would provide better dispersion of the fibers, due to decreasing the viscosity of the mix (Bourland, 1988). Proflow 1000 is an isotactic homopolymer with a melting point of 161°C, while Proflow 3000 is an isotactic copolymer with a melting point of 142°C. The Proflow resins have a narrow molecular weight distribution centered around a peak of 40,000, which allows them to be useful as unique flow and processing modifiers. The structure of the Proflow resins can be found in Appendix D.

Methods

To form the composite each additive was first mixed with the granulated HDPE. In order to establish a good mixture, the bag containing the additive and HDPE was thoroughly shaken. All composites were approximately 40% by weight Aspen hardwood fibers. The effects of Surlyn and MAPP were studied at approximately 1%, 3%, and 5% weight ratios. The effects of Proflow 1000 and Proflow 3000 were studied utilizing approximately 5% additive. Duplicate batches of each composite concentrations were run. (See appendix A for actual concentrations of constituents incorporated in the composites).

The wood fibers and HDPE were combined in a co-rotating twin screw extruder (Baker Perkin Model MPC/V-30 DE, 38 mm, 13:1). The extruder is heated in three sections called zones. The left section is called zone 1, the middle section is called zone 2, and the right section is called zone 3. The die, which is where the material exists the extruder, is also heated and is connected to the end of zone 3. The parameters of the extruder were set as follows: compounder speed, 200 rpm's; compounder % load, 105; discharge pressure, 900; discharge temperature, 150°C; barrel valve, 15; feed rate, 3. The three extruder zones including the die were all preheated to 150°C. This temperature was maintained throughout the extrusion process by the use of water as a coolant. After

thoroughly mixing the additive with HDPE, the mixture was placed in the extruder's hopper. HDPE regrind was fed into zone 1 of the extruder for approximately 20 minutes. This ensured that the extruder zones did not contain any unwanted contaminants. The polymer was then conveyed from the hopper to the extruder and pre-melted in zone 1. The advantages of adding the fibers to a pre-melted polymer are to reduce fiber damage and gain better dispersion.

As the material exited the die, it was cut into approximately 12 cm lengths. The extruded material was compression molded into sheets. The compression molding was done using a Carver laboratory press compression molding machine, model M25 ton. The temperature of the upper and lower platens was set to 150°C and the press was allowed to preheat for 15 minutes. For tensile and creep testing, three lengths of material were placed in a 15 x 15 x 0.25 cm frame. Chrome plates approximately 18 x 18 cm were placed underneath and over the frame and lengths of material to form a flat sheet from the extrudate, during compression molding. Mylar was also used between the chrome plates and frame to minimize sticking. This configuration was known as a "sandwich".

The "sandwich" was placed on the lower platen and after closing the hydraulic chamber, pressure was applied gradually until it reached 30,000 psi. The "sandwich" was kept under

pressure for approximately ten minutes. The temperature was reduced to room temperature and water was used to cool the compression molded sheet. After fifteen minutes of cooling the pressure was released and the "sandwich" was removed. The same procedure was used to compression mold sheets for impact and water sorption tests, except the "sandwich" was formed with a 12.7 x 12.7 x 0.3175 cm frame and two lengths of material. Approximately three sheets can be compression molded from 300 grams of material.

Tensile properties were determined following ASTM standard P 638 -86, Standard Test Method for Tensile Properties of Plastics. The test was performed on dumbbell-shaped Type I specimens. To achieve the dimensions specified in the standard, the sheets were first cut into 0.75 in. (1.91 cm) thick strips. Then a tensilkut cutting machine was employed to achieve the dumbbell shape with a narrow section measuring 0.5 in. (1.27 cm). The specimens were conditioned at 23 $\pm$ 2°C and 50 $\pm$ 5% RH for not less than 40 hrs, before being tested. The specimens were tested on an Instron Tester Model 4201 at ambient conditions (23°C, 50% RH). The parameters of the Instron were set as follow: full scale load of 400 lbs., chart speed of 2 in./min, and crosshead speed of 2 in./min. Sandpaper was used on the sample ends in order to avoid slippage of the specimens in the grips. In accordance with the standard, specimens that did not break within the narrow

section were discarded. Tensile strength, % elongation at break, and modulus of elasticity were calculated using the following formulas:

$$\text{Tensile Strength} = \frac{\text{Maximum Force}}{\text{Original Minimum Cross-sectional Area}} \quad (15)$$

$$\%\ \text{Elongation at Break} = \frac{\text{Peak Extension}}{\text{Original Gage Length}} \times 100 \quad (16)$$

$$\text{Modulus of Elasticity} = \frac{\text{Stress}}{\text{Strain}} \quad (17)$$

where: $$\text{Stress} = \frac{\text{Force}}{\text{Original Minimum Cross-sectional Area}}$$

$$\text{Strain} = \frac{\text{Change in Length}}{\text{Original Gage length}}$$

Izod impact strength was determined following ASTM Standard D 256 -81, Standard Test Method for Impact Resistance of Plastics and Electrical Insulating Materials. To achieve the dimensions specified in the standard, the sheets were cut into 0.5 x 2.5 in. (1.27 x 6.35 cm) strips. The specimens were notched using the TMI Notching Cutter. When the specimen is notched, it will exhibit a brittle fracture rather than a ductile fracture. The specimens were conditioned at 23 $\pm$ 2°C and 50 $\pm$ 5% RH for not less than 40 hrs., before being tested. The specimens were tested on a TMI 43-1 Izod Impact Tester with a 5 ft-lb pendulum load at ambient conditions. The

Impact Tester was calibrated, then the sample was positioned in the clamp with a jig. The pendulum was released and the type of break and impact strength in ft.lb./in. was recorded.

Water absorption was determined following ASTM Standard D 570 - 81, Standard Test Method for Water Absorption of Plastics. The test specimens were in the form of disks 2 in. (5.1 cm) in diameter and 0.125 in. (0.3175 cm) in thickness. The samples were conditioned by drying them in an oven for 24 hr at 50 $\pm$ 3°C, cooling them in a desiccator, and then immediately weighing them to the nearest 0.001 g. The 2-hr boiling water immersion procedure was used to determine water absorption. The conditioned specimens were placed in a container of boiling distilled water for 120 $\pm$ 4 minutes. Throughout the test the specimens were supported on edge and kept completely immersed by a series of racks. After the allotted time, the specimens were withdrawn one at a time, all surface water removed, and weighed to the nearest 0.001 g immediately. The increase in weight, in %, was calculated by the following equation:

$$\text{Increase in weight, \%} = \frac{\text{Wet wt. - Conditioned wt.}}{\text{Conditioned wt.}} \times 100 \qquad (18)$$

Creep analysis was determined following ASTM Standard D 2990 - 77, Standard Test Methods for Tensile, Compressive, and

Flexural Creep and Creep-Rupture of Plastics. The specimens were cut identical to the specimens used to measure tensile properties. Grips were attached to each end of the sample. Sandpaper was used in order to avoid slippage of the specimens. Fifty pound weights were attached to the bottom of the end grips and creep extension was measured at set increments specified in the standard, up to 700 hrs. The specimens were conditioned prior to the test, at 23 $\pm$ 2°C and 50 $\pm$ 5% RH for not less than 40 hrs. Creep extension was measured by grip separation. The increase in length, in %, was calculated by the following equation:

$$\text{Increase in Length, \%} = \frac{\text{Final Length - Original Length}}{\text{Original Length}} \times 100 \qquad (19)$$

Results and Discussion

Results - Tensile Properties

Results - Tensile Strength

The results of tensile strength are tabulated in Table 2 and presented graphically in Figure 1. Statistical analysis comparing batch 1 and batch 2 confirmed that there was not a significant difference between the batches, therefore the batches were combined. As can be seen from Figure 1 the addition of MAPP increased tensile strength at all levels. Statistical analysis resulted in a highly significant treatment effect at all levels, with the addition of MAPP at an alpha level of 0.05. Addition of 1% and 5% Surlyn produced some positive results in tensile strength, but not at a statistically significant level. Addition of Proflow 1000 had little effect positive or negative, which was confirmed with statistical analysis. Statistical analysis resulted in a non-significant t value at an alpha level of 0.05. Addition of Proflow 3000 decreased the tensile strength of the composites. Statistical analysis confirmed that this was a significant decrease. Compared to the composite without additives, the highest increase in tensile strength occurred with the inclusion of 5% MAPP and was approximately 38.9%. (See Appendix B for data and Appendix C for statistical analysis)

Table 2. Results of Tensile Strength

TENSILE STRENGTH ($N/m^2 \times 10^{+7}$)		
MATERIAL	MEAN	STD
60% HDPE, 40% FIBER	2.02	0.40
1% MAPP, 59% HDPE, 40% FIBER	2.91	0.30
3% MAPP, 57% HDPE, 40% FIBER	2.49	0.21
5% MAPP, 55% HDPE, 40% FIBER	3.30	0.48
1% SURLYN, 59% HDPE, 40% FIBER	2.03	0.53
3% SURLYN, 57% HDPE, 40% FIBER	1.83	0.25
5% SURLYN, 55% HDPE, 40% FIBER	2.08	0.25
5% PROFLOW 1000, 55% HDPE, 40% FIBER	1.97	0.26
5% PROFLOW 3000, 55% HDPE, 40% FIBER	1.68	0.27

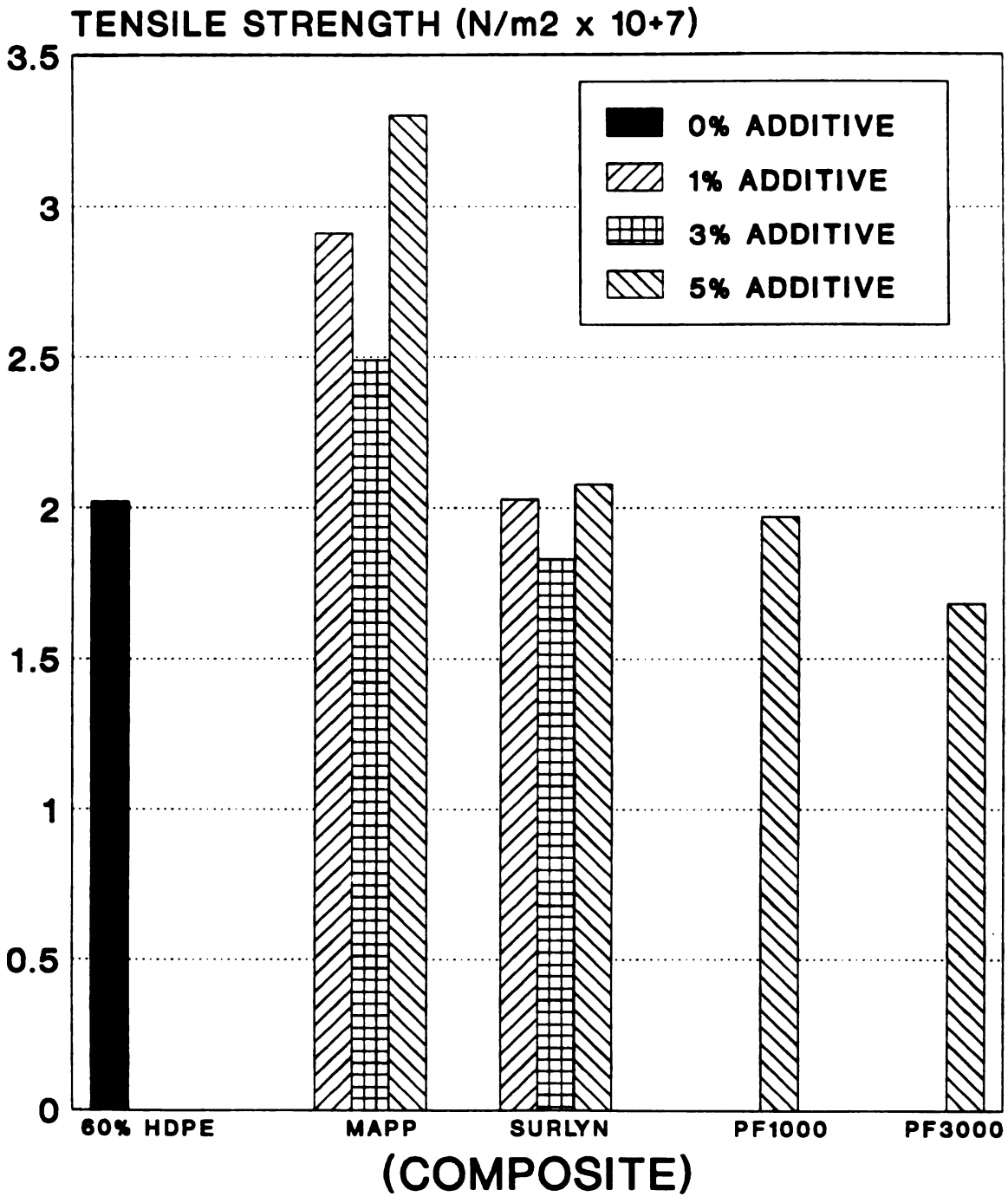


Figure 1. Tensile Strength

Results - Modulus of Elasticity

The values determined for modulus of elasticity are tabulated in Table 3 and presented graphically in Figure 2. Statistical analysis comparing batch 1 and batch 2 confirmed that there was not a significant difference between the batches, therefore the batches were combined. As can be seen from Figure 2, inclusion of nearly all the additives produced positive results for modulus of elasticity. For MAPP as the level of additive incorporated increased the modulus of elasticity increased, but only addition of 5% MAPP was found to be significantly different from the composite without additives. For Surlyn, modulus of elasticity increased at all levels, with the greatest increase noted at addition of 3% additive. Also, compared to the composite without additives, significant differences were found at inclusion of 3% and 5% Surlyn at an alpha level of 0.05. Addition of Proflow 1000 and Proflow 3000 produced some positive results, but neither additive was found to be significantly different from the composite without additives. As with tensile strength, inclusion of 5% MAPP produced the highest increase in modulus of elasticity and was approximately 13.9%. (See Appendix B for data and Appendix C for statistical analysis)

Table 3. Results of Modulus of Elasticity

MODULUS OF ELASTICITY ($N/m^2 \times 10^{+8}$)		
MATERIAL	MEAN	STD
60% HDPE, 40% FIBER	7.91	1.05
1% MAPP, 59% HDPE, 40% FIBER	7.04	2.09
3% MAPP, 57% HDPE, 40% FIBER	7.71	0.76
5% MAPP, 55% HDPE, 40% FIBER	9.19	1.17
1% SURLYN, 59% HDPE, 40% FIBER	8.68	1.01
3% SURLYN, 57% HDPE, 40% FIBER	9.18	0.98
5% SURLYN, 55% HDPE, 40% FIBER	9.10	0.96
5% PROFLOW 1000, 55% HDPE, 40% FIBER	8.37	0.71
5% PROFLOW 3000, 55% HDPE, 40% FIBER	8.00	0.74

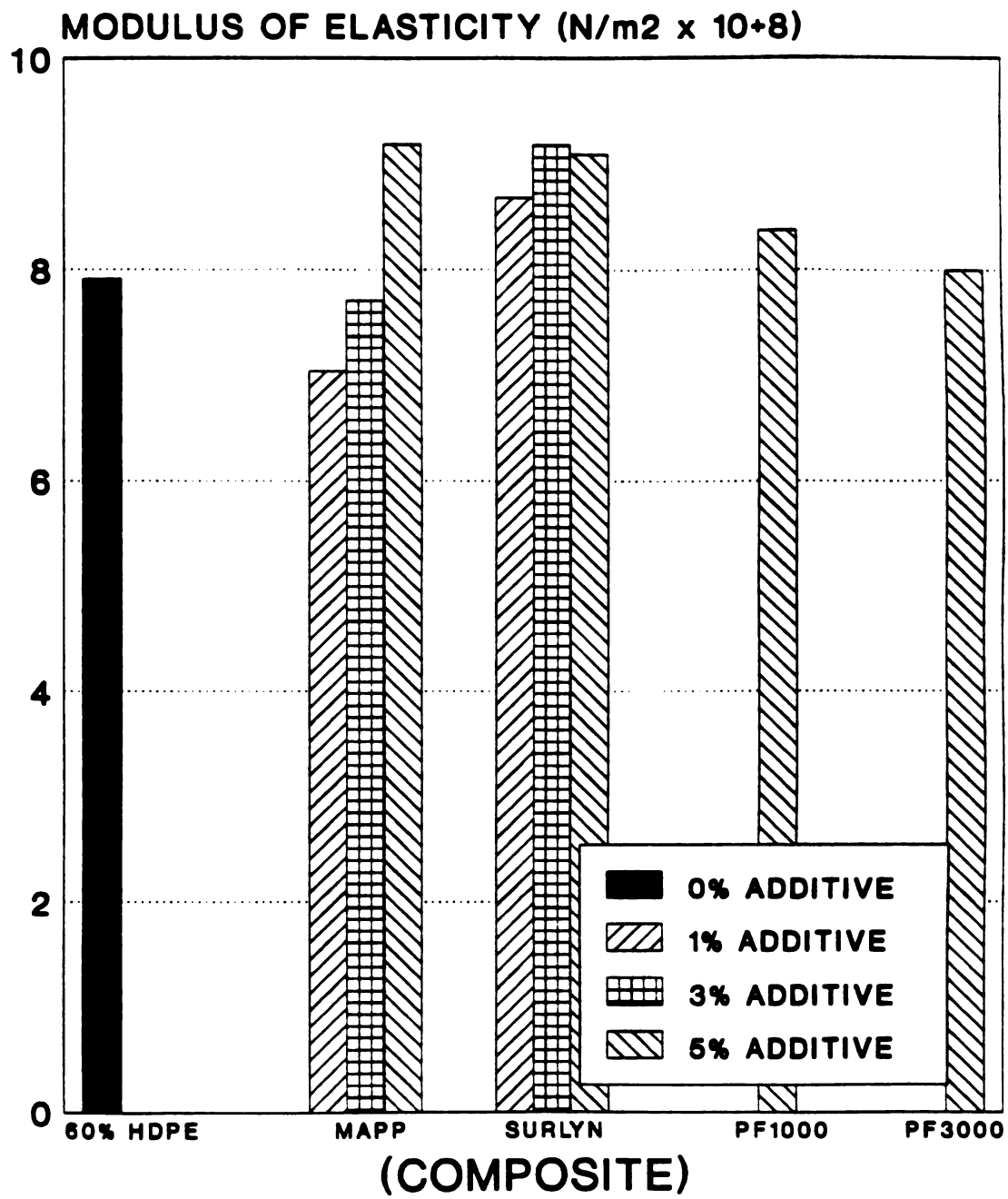


Figure 2. Modulus of Elasticity

Results - % Elongation at Break

Values determined for % elongation at break are summarized in Table 4 and presented graphically in Figure 3. Statistical analysis comparing batch 1 and batch 2 confirmed that there was not a significant difference between the batches, therefore the batches were combined. The inclusion of MAPP resulted in an increase in % elongation at all levels. A significant treatment effect was found with addition of 3% MAPP, while highly significant treatment effects were found with inclusion of 1% and 5% MAPP at an alpha level of 0.05. As with tensile strength, incorporating 1% and 5% Surlyn produced some positive results in % elongation, but not at a statistically significant level. Although addition of 3% Surlyn resulted in a significant decrease in % Elongation at an alpha level of 0.05. Inclusion of Proflow 1000 and Proflow 3000 had little effect on % elongation and was confirmed through statistical analysis. The greatest increase in % elongation for all additives occurred with the inclusion of 5% MAPP and was approximately 42.1%. (See Appendix B for data and Appendix C for statistical analysis)

Table 4. Results of % Elongation at Break

ELONGATION AT BREAK (%)		
MATERIAL	MEAN	STD
60% HDPE, 40% FIBER	3.81	0.93
1% MAPP, 59% HDPE, 40% FIBER	6.13	0.70
3% MAPP, 57% HDPE, 40% FIBER	5.06	1.02
5% MAPP, 55% HDPE, 40% FIBER	6.58	1.82
1% SURLYN, 59% HDPE, 40% FIBER	4.06	1.56
3% SURLYN, 57% HDPE, 40% FIBER	3.01	0.50
5% SURLYN, 55% HDPE, 40% FIBER	3.85	0.65
5% PROFLOW 1000, 55% HDPE, 40% FIBER	3.52	0.67
5% PROFLOW 3000, 55% HDPE, 40% FIBER	3.14	0.60

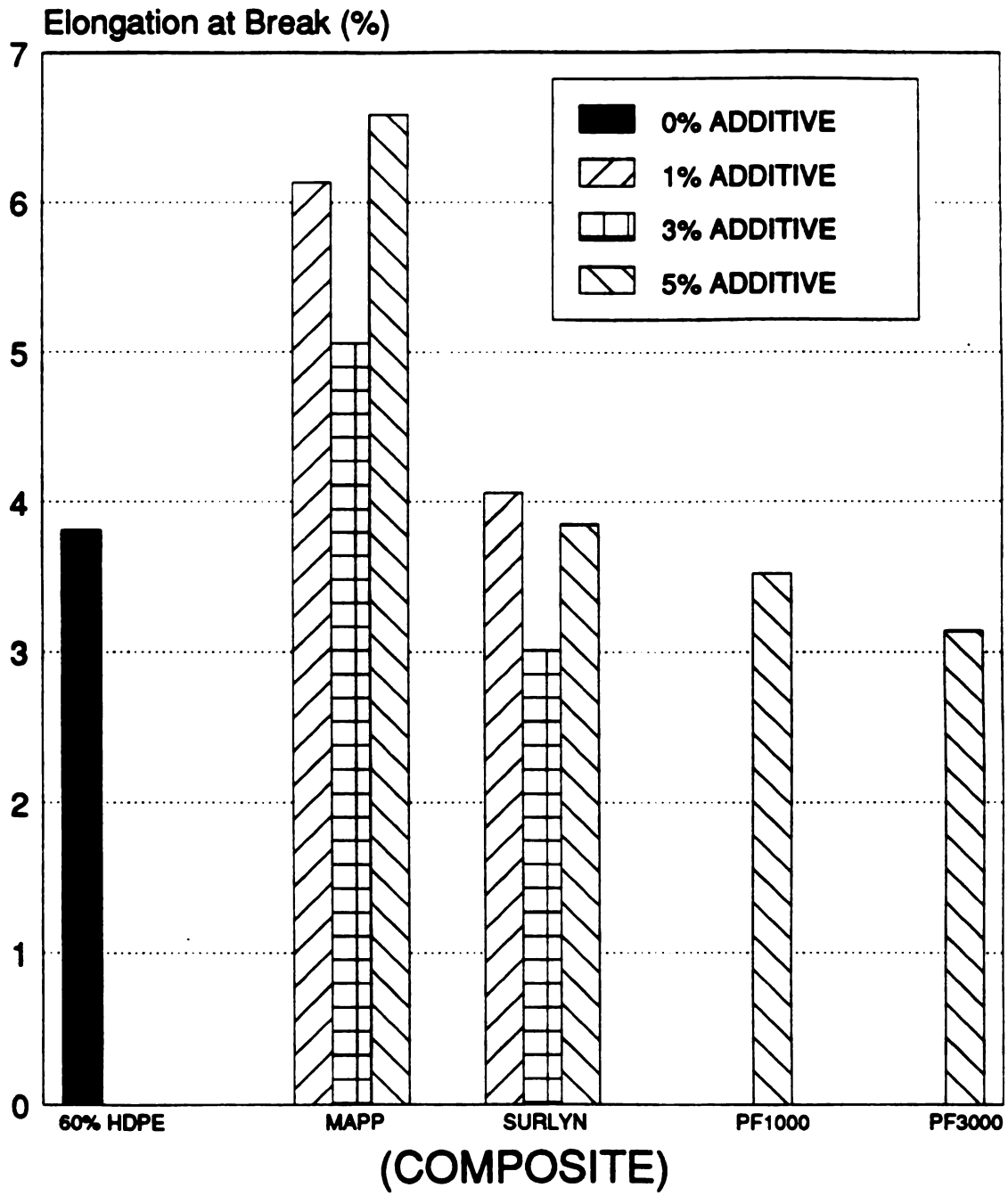


Figure 3. % Elongation at Break

Discussion - Tensile Properties

The tensile test has the ability to demonstrate the composite's overall mechanical strength, which can give an indication of the way the composite will perform in other tests. For these reasons the tensile test is considered the most important test the composite material must endure. The data obtained from tensile tests are very useful for qualitative characterization. There are a number of variables that influence the properties of fibrous reinforced composite materials and structures: (1) the interfacial bond between the matrix and fibers, (2) the properties, size, shape, loading, and alignment of the fibers, and (3) processing technique (Richardson, 1987). The ability of the matrix to efficiently transfer stress to the fibers is increased with increased adhesion between the matrix and the fibers. Using MAPP as an additive in prior studies (Nieman, 1989 and Keal 1990) has shown its ability to enhance tensile properties. This study also showed MAPP's ability to enhance tensile properties. MAPP is a coupling agent and very small amounts of coupling agents have been shown to enhance mechanical properties considerably. These results confirm MAPP's potential for improving the adhesion between the recycled HDPE and wood fibers. Dispersion of the fibers is also a factor influencing stress transfer, but seems to only be a secondary concern. It is probably a secondary concern because adequate dispersion of the fibers is achieved during processing. Also, although

better dispersion allows the fibers to be "wetted out" this does not mean that it will promote good adhesion between incompatible phases. The results obtained from this study seem to confirm this theory. Proflow 1000 and Proflow 3000 are dispersants but did not enhance the tensile properties of the composite. This may be due to achieving good dispersion, while failing to obtain good adhesion between the two phases.

Results - Izod Impact Strength

Results determined from Izod Impact Strength are summarized in Table 5 and presented graphically in Figure 4. Statistical analysis comparing batch 1 and batch 2 confirmed that there was not a significant difference between the batches, therefore the batches were combined. As can be seen from Figure 4, the inclusion of all additives decreased the impact strength compared to the composite without additives. The decrease in impact strength was found to be significantly different for all additives at an alpha level of 0.05. Incorporating Proflow 1000 into the composite resulted in the greatest decrease in impact strength. For MAPP and Surlyn the greatest decrease in impact strength was noted at 3% and 5% levels respectively. (See Appendix B for data and Appendix C for statistical analysis)

Table 5. Results Izod Impact Strength

IZOD IMPACT STRENGTH (J/m)		
MATERIAL	MEAN	STD
60% HDPE, 40% FIBER	52.52	7.65
1% MAPP, 59% HDPE, 40% FIBER	47.83	5.15
3% MAPP, 57% HDPE, 40% FIBER	45.10	4.77
5% MAPP, 55% HDPE, 40% FIBER	45.69	5.96
1% SURLYN, 59% HDPE, 40% FIBER	42.97	6.07
3% SURLYN, 57% HDPE, 40% FIBER	42.61	5.61
5% SURLYN, 55% HDPE, 40% FIBER	42.61	5.01
5% PROFLOW 1000, 55% HDPE, 40% FIBER	39.96	5.75
5% PROFLOW 3000, 55% HDPE, 40% FIBER	42.84	7.01

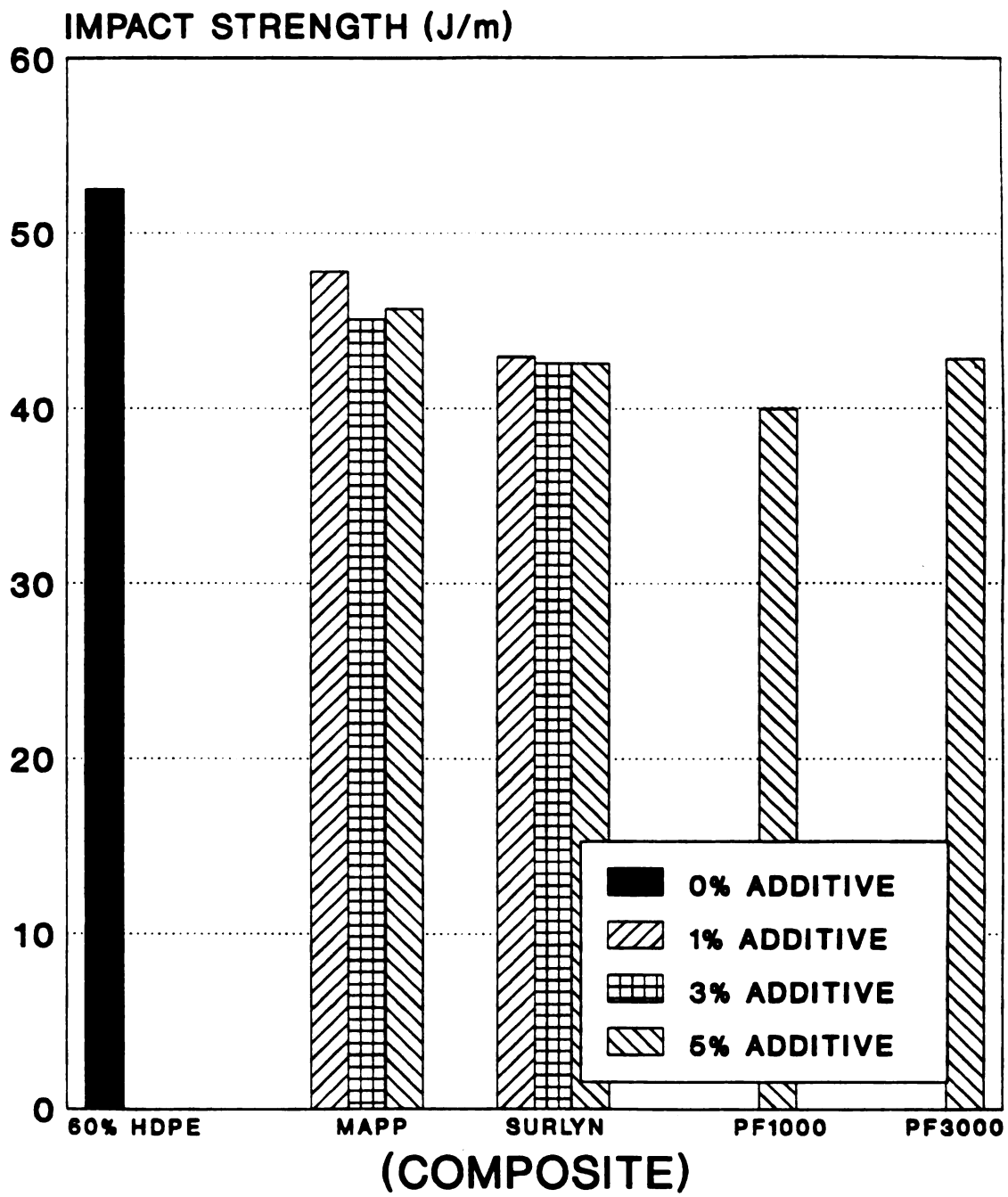


Figure 4. Izod Impact Strength

Discussion - Izod Impact Strength

The impact test is the most common method of measuring toughness of plastics and composites in industry. The most common test methods are Izod, Charpy, tensile impact, and falling weight. These tests are basically qualitative in that they allow the specimens to be graded. An Izod impact test determines a material's resistance to breakage by flexural shock. The material's toughness, breaking properties, and deformation are measured by the energy required to rupture the test specimen. Although the relationship between matrix, filler, and interfacial strength is not as yet resolved, there are theories to explain the mechanisms that may be involved in decreasing the impact strength of fibrous composites. One source explains that while good adhesion improves strength, it increases the tendency to brittle failure and makes the material more notch sensitive (Richardson, 1977). Another source explains the strength/toughness dilemma in terms of ductile and brittle matrices. For ductile materials Agarwal and Broutman (1980) believe that triaxial restraint of the matrix between fiber, limits elongation of the matrix which greatly reduces toughness. But for brittle matrices, they believe the addition of fibers to the matrix can increase toughness, because of crack blunting, branching, and arrest effects.

Results - Water Absorption

Water Absorption results are tabulated in Table 6 and presented graphically in Figure 5. Statistical analysis comparing batch 1 and batch 2 confirmed that there was not a significant difference between the batches, therefore the batches were combined. It can be seen from Figure 5 that the inclusion of MAPP and Proflow 1000 impeded water sorption of the specimens. Statistical analysis resulted in a highly significant treatment effect at all levels, with the addition of MAPP at an alpha level of 0.05. The composite with Proflow 1000 was found to be significantly different from the composite without additives. Surlyn and Proflow 3000 appeared to promote water sorption. For Surlyn, the amount of water being sorbed increased as the level of additive increased. At 1% Surlyn, 3% Surlyn, and 5% Proflow 3000, although there was a slight increase in the amount of water being sorbed, neither additive was found to be significantly different from the composite without additives. At 5% Surlyn, the increase in the amount of water being sorbed was found to be a highly significant increase. All three levels of MAPP sorbed less water than all of the other composites, with 3% MAPP producing the best results. The composite containing 3% MAPP sorbed approximately 51.8% less water than the composite without additive. (See Appendix B for data and Appendix C for statistical analysis)

Table 6. Results of Water Absorption

WATER ABSORPTION (% INCREASE IN WEIGHT)		
MATERIAL	MEAN	STD
60% HDPE, 40% FIBER	2.11	0.51
1% MAPP, 59% HDPE, 40% FIBER	1.27	0.35
3% MAPP, 57% HDPE, 40% FIBER	1.02	0.11
5% MAPP, 55% HDPE, 40% FIBER	1.22	0.14
1% SURLYN, 59% HDPE, 40% FIBER	2.16	0.20
3% SURLYN, 57% HDPE, 40% FIBER	2.31	0.32
5% SURLYN, 55% HDPE, 40% FIBER	2.91	0.27
5% PROFLOW 1000, 55% HDPE, 40% FIBER	1.42	0.56
5% PROFLOW 3000, 55% HDPE, 40% FIBER	2.26	0.17

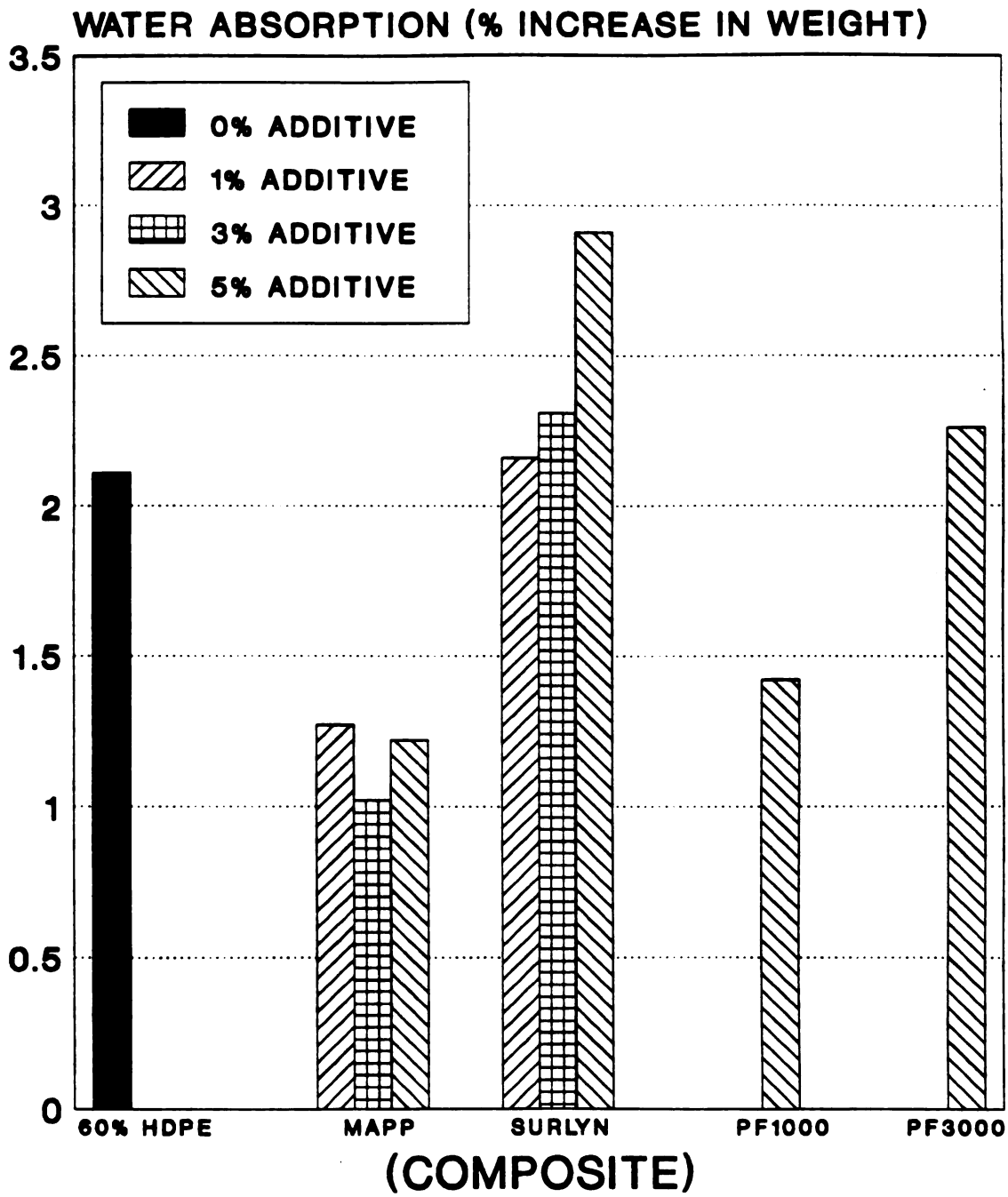


Figure 5. Water Absorption

Discussion - Water Absorption

The test for rate of water absorption has two chief functions: first, as a guide to the proportion of water absorbed by a material and consequently, in those cases where the relationship between moisture and electrical or mechanical properties, dimensions, or appearance have been determined, as a guide to the effects of exposure to water or humid conditions on such properties; and second as a control test on the uniformity of a product (ASTM D 570, 1987). As explained earlier wood fibers are hydrophilic in nature which means they attract water. The water interacts with the hydroxyl groups present in the fibers. This can result in a decrease in mechanical properties. Techniques can be utilized to overcome this problem. First and foremost is good adhesion between the matrix and filler. Good adhesion between the two phases will decrease the amount of available hydroxyl groups to react with the water. Use of a coupling agent has been shown to decrease the amount of water sorbed due to increased adhesion between the two phases. Secondly, chemically treating the fibers with a water resistant coating can also help in decreasing water absorption. MAPP resulted in the least amount of water being sorbed, which indicates that MAPP may be improving the adhesion between the two phases. But since water was sorbed, there may still be some unbonded hydroxyl groups available to sorb water molecules.

Results - Creep

Results of creep extension are summarized in Table 7 and presented graphically in Figure 6. Creep analysis was performed on only one batch (two samples) of the composites containing 3% MAPP and 5% Proflow 1000. One of the samples broke before the test was completed, for the composites containing 1% Surlyn and 5% Proflow 3000. Due to varying sample sizes, statistical analysis was not performed on this data, but the data available for each composite was combined. Therefore, the results obtained are suggestive rather than conclusive. As can be seen from Figure 6, although all the composites experienced creep extension, MAPP and Surlyn at 5% levels exhibited the least amount of creep for all the composites. Addition of 5% MAPP resulted in a decrease in creep of approximately 24.6% as compared to the composite without additive, while the addition of 5% Surlyn decreased creep by approximately 27.5%. The batch of Proflow 1000 tested also resulted in a slight decrease in creep extension. (See appendix B for data)

Table 7. Results Creep Extension

CREEP (% INCREASE IN LENGTH)		
MATERIAL	MEAN	STD
60% HDPE, 40% FIBER	0.63	0.16
1% MAPP, 59% HDPE, 40% FIBER	0.87	0.27
3% MAPP, 57% HDPE, 40% FIBER	0.69*	
5% MAPP, 55% HDPE, 40% FIBER	0.56	0.13
1% SURLYN, 59% HDPE, 40% FIBER	0.69	0.16
3% SURLYN, 57% HDPE, 40% FIBER	0.63	0.32
5% SURLYN, 55% HDPE, 40% FIBER	0.45	0.04
5% PROFLOW 1000, 55% HDPE, 40% FIBER	0.59*	
5% PROFLOW 3000, 55% HDPE, 40% FIBER	0.71	0.08

*ONLY TWO SAMPLES OF THESE COMPOSITES WERE TESTED, THEREFORE STANDARD DEVIATION COULD NOT BE CALCULATED

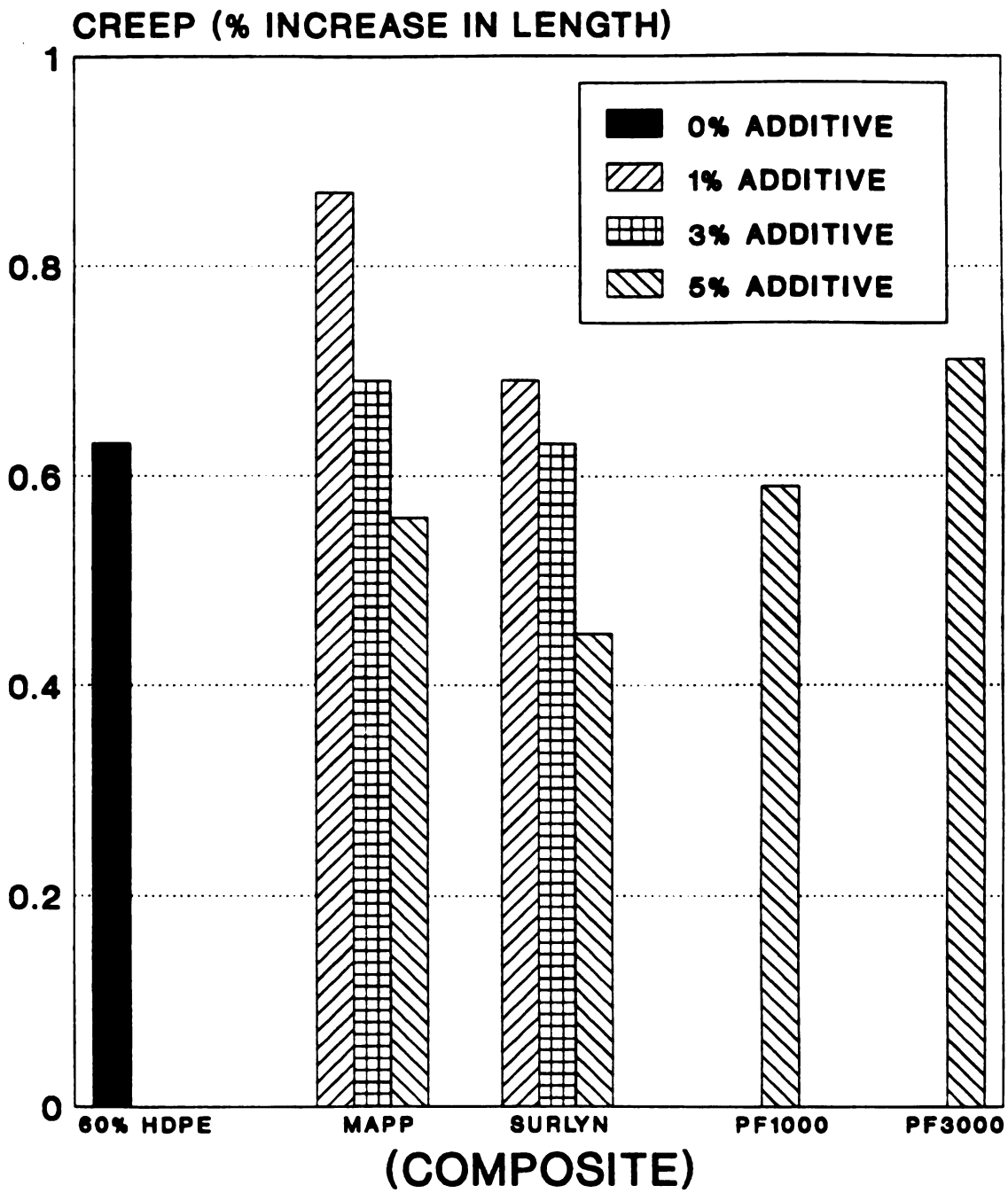


Figure 6. Creep Extension

Discussion - Creep

The results determined from creep tests are necessary to predict the strength and dimensional changes of materials under load. The results obtained can be used in the design of parts, to compare materials, and to characterize the performance of materials subjected to long term loading. By incorporating fibers in the matrix, creep can be reduced. The addition of fibers reduces the amount of matrix material available for creep and allows the material to endure loads for extended periods of time. For this reason a strong interfacial bond between matrix and fibers is needed. The fibers in a composite with a strong interfacial bond will not pull out very easily. MAPP and Surlyn at 5% levels exhibited the lowest creep extension of all the composites. This suggests as all tests have that MAPP is promoting strong interfacial bonding.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The inclusion of MAPP in the composite improved its mechanical properties overall. Tensile strength and % elongation were increased with the addition of MAPP at all levels, with the most significant increase for all additives occurring with inclusion of 5% MAPP. The highest increase in modulus of elasticity also occurred with 5% inclusion of MAPP. Addition of MAPP impeded water sorption at all levels, compared to any of the composites tested. Also, addition of 5% MAPP resulted in a decrease in creep of approximately 24.6%. As with all additives inclusion of MAPP decreased impact strength.

The inclusion of Surlyn produced some positive effects on mechanical properties. Addition of 1% and 5% Surlyn slightly increased tensile strength and % elongation. Modulus of elasticity increased at all levels of Surlyn, with the greatest increase noted at 3% additive. Surlyn seemed to promote water sorption, with the amount of water being sorbed increasing with increasing level of additive. Addition of 5% Surlyn decreased creep by approximately 27.5%. Again, as with all additives inclusion of Surlyn decreased impact strength.

The inclusion of Proflow 1000 and Proflow 3000 generally decreased the mechanical properties of the composites. The addition of both additives decreased the tensile strength and

% elongation of the composites. The addition of both additives slightly increased modulus of elasticity. Proflow 1000 impeded water sorption while Proflow 3000 appeared to promote it. Proflow 1000 slightly decreased the amount of creep experienced by the samples, while Proflow 3000 increased it. As stated earlier, inclusion of all additives decreased impact strength.

The inclusion of MAPP in the composites enhanced its mechanical properties. This was shown not only in comparison to the composite without additives, but also any of the additives utilized in this investigation. The ability of MAPP to enhance mechanical properties supports the theory of it having the potential, to improve adhesion between the matrix and fibers. A strong interfacial bond between the fibers and matrix allows the matrix to efficiently transfer stress to the fibers. Also a strong interfacial bond can prevent the propagation of microcracks along the fiber lengths.

Although MAPP produced the best results in this study, it is the most expensive (see table 1) of all the additives utilized. This may be a concern because when using recycled materials to manufacture a product, it is important to reduce the cost of manufacture as much as possible, in order to compete with other recycled or virgin materials.

RECOMMENDATION FOR FURTHER RESEARCH

Further investigation is warranted for the Proflow resins, in order to validate the findings of this investigation. In order to obtain conclusive results for creep a more representative sample size is recommended for this test. Upon researching composite materials composed of wood fibers and polymers, it was found that multiple additives were used in order to enhance mechanical properties. Since Surlyn and Proflow 1000 produced some positive effects on mechanical properties, it may be beneficial to investigate the effect of an additive system composed of MAPP, Surlyn, and Proflow 1000.

APPENDIX A

APPENDIX A

Table 8. Concentrations of Composite Components

ACTUAL CONCENTRATIONS OF COMPOSITE COMPONENTS (%)			
COMPOSITE	ADDITIVE	WOOD FIBER	HDPE
60%-HDPE-BATCH 1	0.00	59.23	40.77
60%-HDPE-BATCH 2	0.00	58.86	41.14
1%-MAPP-BATCH 1	0.98	58.00	41.02
1%-MAPP-BATCH 2	0.98	58.04	40.98
3%-MAPP-BATCH 1	2.96	56.29	40.75
3%-MAPP-BATCH 2	2.95	56.10	40.95
5%-MAPP-BATCH 1	4.90	53.95	41.15
5%-MAPP-BATCH 2	4.92	54.12	40.96
1%-SURLYN-BATCH 1	0.97	57.44	41.59
1%-SURLYN-BATCH 2	0.97	57.55	41.48
3%-SURLYN-BATCH 1	2.93	55.70	41.37
3%-SURLYN-BATCH 2	2.93	55.58	41.49
5%-SURLYN-BATCH 1	4.91	54.03	41.06
5%-SURLYN-BATCH 2	4.86	53.48	41.66
5%-PF1000-BATCH 1	4.91	54.00	41.09
5%-PF1000-BATCH 2	4.88	53.67	41.45
5%-PF3000-BATCH 1	4.86	53.49	41.65
5%-PF3000-BATCH 2	4.86	53.44	41.70

APPENDIX B

APPENDIX B

Table 9a. Data Tensile Strength

DATA TENSILE STRENGTH Pa (N/m^2 x 10^{+7})					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
BATCH 1					
1	2.91	2.81	2.20	3.17	2.27
2	2.27	2.80	2.60	3.17	1.67
3	2.23	2.61	2.71	3.47	1.97
4	1.62	2.99	2.56	3.16	2.81
5	2.08	2.95	2.33	3.20	2.11
BATCH 2					
1	2.07	3.67	2.43	2.69	1.97
2	1.56	3.02	2.26	4.52	2.91
3	1.68	2.85	2.45	3.44	1.22
4	1.89	2.77	2.87	3.27	1.58
5	1.87	2.67	2.44	2.93	1.74
MEAN	2.02	2.91	2.49	3.30	2.03
STD	0.40	0.30	0.21	0.48	0.53

Table 9b. Data Tensile Strength Cont.

DATA TENSILE STRENGTH Pa ($N/m^2 \times 10^{+7}$)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
BATCH 1				
1	2.26	1.89	2.55	1.32
2	1.67	2.06	2.20	1.74
3	2.03	2.35	1.84	2.26
4	2.08	2.19	1.63	1.80
5	1.49	1.90	1.85	1.57
BATCH 2				
1	1.98	2.03	2.05	1.55
2	1.66	2.52	1.81	1.53
3	1.84	1.64	1.87	1.58
4	1.72	1.98	1.90	1.52
5	1.58	2.20	2.00	1.95
MEAN	1.83	2.08	1.97	1.68
STD	0.25	0.25	0.26	0.27

Table 10a. Data Modulus of Elasticity

DATA MODULUS OF ELASTICITY Pa ($N/m^2 \times 10^{+8}$)					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
BATCH 1					
1	9.40	4.96	6.97	7.90	8.16
2	8.15	7.44	8.02	11.67	8.14
3	8.91	8.17	7.40	9.15	9.52
4	6.51	7.51	6.58	9.05	10.41
5	6.98	8.31	7.88	10.83	9.48
BATCH 2					
1	7.16	9.72	6.97	8.55	7.81
2	6.84	8.78	8.22	9.00	9.77
3	7.92	6.91	9.15	8.25	7.45
4	7.92	7.82	7.65	8.62	8.10
5	9.35	6.78	8.26	8.90	7.98
MEAN	7.91	7.04	7.71	9.19	8.68
STD	1.05	2.09	0.76	1.17	1.01

Table 10b. Data Modulus of Elasticity Cont.

DATA MODULUS OF ELASTICITY Pa ($N/m^2 \times 10^{+8}$)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
BATCH 1				
1	8.73	9.15	9.05	7.37
2	9.01	9.98	7.94	6.81
3	7.87	10.28	7.81	7.59
4	11.04	8.98	8.73	8.68
5	9.37	7.68	7.26	7.82
BATCH 2				
1	10.49	8.43	8.28	7.41
2	8.23	7.97	9.67	8.01
3	8.48	8.41	8.54	8.44
4	9.18	9.86	8.66	9.08
5	9.37	10.27	7.74	8.83
MEAN	9.18	9.10	8.37	8.00
STD	0.98	0.96	0.71	0.74

Table 11a. Data % Elongation at Break

DATA ELONGATION AT BREAK (%)					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
BATCH 1					
1	5.45	6.40	4.50	6.30	4.10
2	4.40	5.35	5.40	5.85	2.85
3	4.60	5.20	5.40	7.00	3.75
4	3.45	7.25	6.45	5.85	4.65
5	4.65	5.95	4.50	5.80	3.40
BATCH 2					
1	3.75	6.55	5.80	4.50	3.80
2	3.05	5.80	3.55	11.30	4.95
3	2.50	7.15	3.80	6.70	2.10
4	3.35	5.80	6.45	6.95	3.15
5	2.90	5.85	4.70	5.55	7.80
MEAN	3.81	6.13	5.06	6.58	4.06
STD	0.93	0.70	1.02	1.82	1.56

Table 11b. Data % Elongation at Break Cont.

DATA ELONGATION AT BREAK (%)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
BATCH 1				
1	3.60	3.45	4.75	2.65
2	2.90	3.80	4.20	3.75
3	3.90	4.65	3.20	4.40
4	2.85	4.05	2.75	3.05
5	2.30	3.60	4.00	3.05
BATCH 2				
1	2.95	3.85	3.60	3.05
2	2.55	5.15	2.60	2.45
3	3.45	2.90	3.20	3.05
4	2.75	3.55	3.10	2.50
5	2.80	3.45	3.75	3.40
MEAN	3.01	3.85	3.52	3.14
STD	0.50	0.65	0.67	0.60

Table 12a. Data Izod Impact Strength

DATA IMPACT STRENGTH (J/m)					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
BATCH 1					
1	53.33	41.58	53.59	47.40	48.74
2	51.24	45.59	39.29	49.16	37.74
3	47.08	39.55	56.69	51.78	56.53
4	80.39	51.56	39.29	55.41	47.40
5	47.08	47.56	52.42	36.46	34.11
6	42.97	41.58	45.21	41.58	44.09
7	42.97	43.56	49.22	39.77	31.92
8	47.08	43.56	47.19	52.10	46.97
9	51.24	53.59	46.12	38.06	32.77
10	49.16	47.56	44.30	35.87	45.05
11	55.41	45.59	49.22	41.26	40.25
12	42.97	47.56	40.25	55.41	40.89
13	49.16	39.55	44.30	51.30	52.10
14	47.08	51.56	42.97	49.59	42.70
BATCH 2					
1	55.41	42.97	42.97	47.83	48.36
2	50.76	46.60	42.92	53.49	48.36
3	56.53	41.96	45.80	37.74	42.28
4	49.16	48.74	45.80	45.64	48.36
5	44.84	50.39	36.78	50.44	38.22
6	59.73	54.23	53.75	45.21	42.28
7	54.50	61.07	42.60	48.25	46.33
8	53.17	47.88	45.80	37.21	34.16
9	52.31	53.91	41.26	48.74	48.36

DATA IMPACT STRENGTH (J/m)					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
10	52.42	46.17	45.05	48.31	44.30
11	61.65	52.42	45.05	44.84	34.16
12	63.15	54.23	43.72	44.20	42.28
13	52.31	48.25	41.58	44.84	42.28
14	57.49	50.44	39.82	37.42	42.28
MEAN	52.52	47.83	45.10	45.69	42.97
STD	7.65	5.15	4.77	5.96	6.07

Table 12b. Data Izod Impact Strength Cont.

DATA IMPACT STRENGTH (J/m)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
BATCH 1				
1	44.30	50.02	32.13	44.25
2	36.73	50.02	38.22	40.19
3	34.16	41.90	40.25	42.22
4	47.19	43.93	34.16	48.36
5	34.11	43.93	36.19	50.39
6	49.16	41.90	40.25	44.25
7	41.96	39.93	44.30	42.22
8	49.16	31.87	34.16	50.39
9	51.24	43.93	42.28	36.19
10	46.97	33.90	44.30	44.25

DATA IMPACT STRENGTH (J/m)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
11	34.75	41.90	36.19	44.25
12	39.82	47.99	38.22	34.16
13	36.89	37.90	36.19	38.17
14	53.33	47.99	38.22	40.19
BATCH 2				
1	38.38	39.82	42.97	48.36
2	38.86	46.17	38.86	42.28
3	40.89	39.82	39.18	52.42
4	44.30	44.09	36.78	28.08
5	42.97	39.82	45.05	34.16
6	50.39	37.74	41.58	38.22
7	45.05	46.17	34.75	48.36
8	36.78	52.58	37.74	34.16
9	49.22	48.31	41.26	48.36
10	38.86	41.96	63.15	58.56
11	46.33	44.09	34.75	38.22
12	36.99	35.60	43.72	32.13
13	44.09	41.96	41.58	48.36
14	40.19	37.74	42.33	48.36
MEAN	42.61	42.61	39.96	42.84
STD	5.61	5.01	5.75	7.01

Table 13a. Data Water Absorption

DATA WATER ABSORPTION INCREASE IN WEIGHT (%)					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
BATCH 1					
1	2.46	1.67	1.04	1.16	1.98
2	1.57	1.16	0.90	1.50	2.31
3	1.80	1.74	0.86	1.13	2.29
BATCH 2					
1	2.90	0.90	1.11	1.22	2.03
2	1.74	1.10	1.14	1.19	2.42
3	2.17	1.06	1.04	1.13	1.94
MEAN	2.11	1.27	1.02	1.22	2.16
STD	0.51	0.35	0.11	0.14	0.20

Table 13b. Data Water Absorption Cont.

DATA WATER ABSORPTION INCREASE IN WEIGHT (%)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
BATCH 1				
1	2.24	3.31	0.76	2.33
2	1.77	2.99	0.81	2.58
3	2.74	2.86	1.28	2.16
BATCH 2				
1	2.27	2.58	2.03	2.17
2	2.33	3.06	1.90	2.16
3	2.51	2.66	1.75	2.16
MEAN	2.31	2.91	1.42	2.26
STD	0.32	0.27	0.56	0.17

Table 14a. Data Creep Extension

DATA CREEP EXTENSION INCREASE IN LENGTH (%)					
RUN	60%HDPE	1%MAPP	3%MAPP	5%MAPP	1%SURLYN
BATCH 1					
1	0.82	1.12	-	0.67	0.52
2	0.48	0.72	-	0.67	0.74
BATCH 2					
1	0.53	1.07	0.38	0.41	*
2	0.70	0.56	0.99	0.48	0.82
MEAN	0.63	0.87	0.69	0.56	0.69
STD	0.16	0.27		0.13	0.16

*These samples broke before completion of test
-Creep extension was measured for only one batch of these samples

Table 14b. Data Creep Extension Cont.

DATA CREEP EXTENSION INCREASE IN LENGTH (%)				
RUN	3%SURLYN	5%SURLYN	5%PF1000	5%PF3000
BATCH 1				
1	0.94	0.46	0.60	0.62
2	0.55	0.40	0.58	0.78
BATCH 2				
1	0.82	0.44	-	*
2	0.22	0.50	-	0.74
MEAN	0.63	0.45	0.59	0.71
STD	0.32	0.04		0.08

*These samples broke before completion of test
-Creep extension was measured for only one batch of these samples

APPENDIX C

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% MAPP	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 11 through 20	
Mean:	2.018	Mean:	2.914
Variance:	0.159	Variance:	0.088
Standard Deviation:	0.399	Standard Deviation:	0.296

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.8108
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.3896

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1234
Variance of the difference between the means:	0.0247
Standard Deviation of the difference:	0.1571
t Value:	-5.7027
Degrees of freedom:	18
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.896 plus or minus 0.330 (0.566 through 1.226)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% MAPP	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 21 through 30	
Mean:	2.018	Mean:	2.485
Variance:	0.159	Variance:	0.042
Standard Deviation:	0.399	Standard Deviation:	0.205

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	3.7682
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.0611

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1006
Variance of the difference between the means:	0.0201
Standard Deviation of the difference:	0.1419
t Value:	-3.2920
Degrees of freedom:	18
Probability of t:	0.0041

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.467 plus or minus 0.298 (0.169 through 0.765)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% MAPP	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 31 through 40	
Mean:	2.018	Mean:	3.302
Variance:	0.159	Variance:	0.234
Standard Deviation:	0.399	Standard Deviation:	0.484

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.4742
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.5724

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1968
Variance of the difference between the means:	0.0394
Standard Deviation of the difference:	0.1984
t Value:	-6.4728
Degrees of freedom:	18
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 1.284 plus or minus 0.417 (0.867 through 1.701)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% SURLYN	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 41 through 50	
Mean:	2.018	Mean:	2.025
Variance:	0.159	Variance:	0.281
Standard Deviation:	0.399	Standard Deviation:	0.530

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.7648
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.4103

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.2199
Variance of the difference between the means:	0.0440
Standard Deviation of the difference:	0.2097
t Value:	-0.0334
Degrees of freedom:	18
Probability of t:	0.9737

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.007 plus or minus 0.441 (-0.434 through 0.448)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% SURLYN	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 51 through 60	
Mean:	2.018	Mean:	1.831
Variance:	0.159	Variance:	0.062
Standard Deviation:	0.399	Standard Deviation:	0.248

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.5805
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.1741

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1103
Variance of the difference between the means:	0.0221
Standard Deviation of the difference:	0.1486
t Value:	1.2588
Degrees of freedom:	18
Probability of t:	0.2242

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.187 plus or minus 0.312 (-0.125 through 0.499)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% SURLYN	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 61 through 70	
Mean:	2.018	Mean:	2.076
Variance:	0.159	Variance:	0.063
Standard Deviation:	0.399	Standard Deviation:	0.251

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.5207
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.1846

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1111
Variance of the difference between the means:	0.0222
Standard Deviation of the difference:	0.1490
t Value:	-0.3892
Degrees of freedom:	18
Probability of t:	0.7017

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.058 plus or minus 0.313 (-0.255 through 0.371)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 1000	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 71 through 80	
Mean:	2.018	Mean:	1.970
Variance:	0.159	Variance:	0.065
Standard Deviation:	0.399	Standard Deviation:	0.255

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.4510
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.1979

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1120
Variance of the difference between the means:	0.0224
Standard Deviation of the difference:	0.1496
t Value:	0.3208
Degrees of freedom:	18
Probability of t:	0.7521

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.048 plus or minus 0.314 (-0.266 through 0.362)

Title: TENSILE STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 3000	
Variable 4: Tensile Strength		Variable 4: Tensile Strength	
Cases 1 through 10		Cases 81 through 90	
Mean:	2.018	Mean:	1.682
Variance:	0.159	Variance:	0.072
Standard Deviation:	0.399	Standard Deviation:	0.267

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.2227
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.2498

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1153
Variance of the difference between the means:	0.0231
Standard Deviation of the difference:	0.1519
t Value:	2.2127
Degrees of freedom:	18
Probability of t:	0.0401

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.336 plus or minus 0.319 (0.017 through 0.655)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: BATCH 1		SAMPLE TWO: BATCH 2	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 45		Cases 46 through 90	
Mean:	8.280	Mean:	8.427
Variance:	2.531	Variance:	0.805
Standard Deviation:	1.591	Standard Deviation:	0.897

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	3.1422
Numerator degrees of freedom:	44
Denominator degrees of freedom:	44
Probability:	0.0002

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	0.0741
Standard Deviation of the difference:	0.2723
t Value:	-0.5382
Effective degrees of freedom:	69
Probability of t:	0.5918

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.147 plus or minus 0.543 (-0.397 through 0.690)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% MAPP	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 11 through 20	
Mean:	7.914	Mean:	7.040
Variance:	1.099	Variance:	4.365
Standard Deviation:	1.048	Standard Deviation:	2.089

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	3.9704
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.0522

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	2.7320
Variance of the difference between the means:	0.5464
Standard Deviation of the difference:	0.7392
t Value:	1.1827
Degrees of freedom:	18
Probability of t:	0.2523

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.874 plus or minus 1.553 (-0.679 through 2.427)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% MAPP	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 21 through 30	
Mean:	7.914	Mean:	7.708
Variance:	1.099	Variance:	0.581
Standard Deviation:	1.048	Standard Deviation:	0.763

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.8906
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.3566

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.8404
Variance of the difference between the means:	0.1681
Standard Deviation of the difference:	0.4100
t Value:	0.5025
Degrees of freedom:	18
Probability of t:	0.6214

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.206 plus or minus 0.861 (-0.655 through 1.067)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% MAPP	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 31 through 40	
Mean:	7.914	Mean:	9.192
Variance:	1.099	Variance:	1.363
Standard Deviation:	1.048	Standard Deviation:	1.168

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.2400
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.7539

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	1.2312
Variance of the difference between the means:	0.2462
Standard Deviation of the difference:	0.4962
t Value:	-2.5744
Degrees of freedom:	18
Probability of t:	0.0191

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 1.278 plus or minus 1.043 (0.235 through 2.320)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% SURLYN	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 41 through 50	
Mean:	7.914	Mean:	8.681
Variance:	1.099	Variance:	1.022
Standard Deviation:	1.048	Standard Deviation:	1.011

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.0755
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.9154

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	1.0607
Variance of the difference between the means:	0.2121
Standard Deviation of the difference:	0.4606
t Value:	-1.6651
Degrees of freedom:	18
Probability of t:	0.1132

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.767 plus or minus 0.968 (-0.201 through 1.735)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% SURLYN	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 51 through 60	
Mean:	7.914	Mean:	9.177
Variance:	1.099	Variance:	0.957
Standard Deviation:	1.048	Standard Deviation:	0.978

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.1493
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.8392

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	1.0279
Variance of the difference between the means:	0.2056
Standard Deviation of the difference:	0.4534
t Value:	-2.7856
Degrees of freedom:	18
Probability of t:	0.0122

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 1.263 plus or minus 0.953 (0.310 through 2.216)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% SURLYN	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 61 through 70	
Mean:	7.914	Mean:	9.101
Variance:	1.099	Variance:	0.927
Standard Deviation:	1.048	Standard Deviation:	0.963

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.1859
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.8037

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	1.0131
Variance of the difference between the means:	0.2026
Standard Deviation of the difference:	0.4501
t Value:	-2.6372
Degrees of freedom:	18
Probability of t:	0.0167

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 1.187 plus or minus 0.946 (0.241 through 2.133)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 1000	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 71 through 80	
Mean:	7.914	Mean:	8.368
Variance:	1.099	Variance:	0.502
Standard Deviation:	1.048	Standard Deviation:	0.709

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.1877
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.2591

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.8009
Variance of the difference between the means:	0.1602
Standard Deviation of the difference:	0.4002
t Value:	-1.1336
Degrees of freedom:	18
Probability of t:	0.2718

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.454 plus or minus 0.841 (-0.387 through 1.295)

Title: MODULUS OF ELASTICITY

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 3000	
Variable 6: Modulus		Variable 6: Modulus	
Cases 1 through 10		Cases 71 through 80	
Mean:	7.914	Mean:	8.003
Variance:	1.099	Variance:	0.542
Standard Deviation:	1.048	Standard Deviation:	0.736

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.0289
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.3067

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.8206
Variance of the difference between the means:	0.1641
Standard Deviation of the difference:	0.4051
t Value:	-0.2199
Degrees of freedom:	18
Probability of t:	0.8284

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.089 plus or minus 0.851 (-0.762 through 0.940)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: BATCH 1		SAMPLE TWO: BATCH 2	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 45		Cases 46 through 90	
Mean:	4.431	Mean:	4.264
Variance:	1.557	Variance:	3.402
Standard Deviation:	1.248	Standard Deviation:	1.844

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.1843
Numerator degrees of freedom:	44
Denominator degrees of freedom:	44
Probability:	0.0109

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	0.1102
Standard Deviation of the difference:	0.3320
t Value:	0.5021
Effective degrees of freedom:	77
Probability of t:	0.6169

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.167 plus or minus 0.661 (-0.494 through 0.828)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% MAPP	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 11 through 20	
Mean:	3.810	Mean:	6.130
Variance:	0.870	Variance:	0.483
Standard Deviation:	0.933	Standard Deviation:	0.695

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.8026
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.3932

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.6767
Variance of the difference between the means:	0.1353
Standard Deviation of the difference:	0.3679
t Value:	-6.3065
Degrees of freedom:	18
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 2.320 plus or minus 0.773 (1.547 through 3.093)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% MAPP	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 21 through 30	
Mean:	3.810	Mean:	5.055
Variance:	0.870	Variance:	1.030
Standard Deviation:	0.933	Standard Deviation:	1.015

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.1830
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.8065

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.9501
Variance of the difference between the means:	0.1900
Standard Deviation of the difference:	0.4359
t Value:	-2.8561
Degrees of freedom:	18
Probability of t:	0.0105

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 1.245 plus or minus 0.916 (0.329 through 2.161)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% MAPP	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 31 through 40	
Mean:	3.810	Mean:	6.580
Variance:	0.870	Variance:	3.305
Standard Deviation:	0.933	Standard Deviation:	1.818

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	3.7970
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.0597

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	2.0878
Variance of the difference between the means:	0.4176
Standard Deviation of the difference:	0.6462
t Value:	-4.2867
Degrees of freedom:	18
Probability of t:	0.0004

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 2.770 plus or minus 1.358 (1.412 through 4.128)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% SURLYN	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 41 through 50	
Mean:	3.810	Mean:	4.055
Variance:	0.870	Variance:	2.429
Standard Deviation:	0.933	Standard Deviation:	1.559

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.7907
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.1423

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	1.6498
Variance of the difference between the means:	0.3300
Standard Deviation of the difference:	0.5744
t Value:	-0.4265
Degrees of freedom:	18
Probability of t:	0.6748

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.245 plus or minus 1.207 (-0.962 through 1.452)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% SURLYN	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 51 through 60	
Mean:	3.810	Mean:	3.005
Variance:	0.870	Variance:	0.245
Standard Deviation:	0.933	Standard Deviation:	0.495

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	3.5573
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.0725

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.5576
Variance of the difference between the means:	0.1115
Standard Deviation of the difference:	0.3339
t Value:	2.4106
Degrees of freedom:	18
Probability of t:	0.0268

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.805 plus or minus 0.702 (0.103 through 1.507)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% SURLYN	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 61 through 70	
Mean:	3.810	Mean:	3.845
Variance:	0.870	Variance:	0.416
Standard Deviation:	0.933	Standard Deviation:	0.645

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.0906
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.2871

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.6434
Variance of the difference between the means:	0.1287
Standard Deviation of the difference:	0.3587
t Value:	-0.0976
Degrees of freedom:	18
Probability of t:	0.9234

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.035 plus or minus 0.754 (-0.719 through 0.789)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 1000	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 71 through 80	
Mean:	3.810	Mean:	3.515
Variance:	0.870	Variance:	0.454
Standard Deviation:	0.933	Standard Deviation:	0.674

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.9176
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.3462

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.6622
Variance of the difference between the means:	0.1324
Standard Deviation of the difference:	0.3639
t Value:	0.8106
Degrees of freedom:	18
Probability of t:	0.4282

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.295 plus or minus 0.765 (-0.470 through 1.060)

Title: % ELONGATION AT BREAK

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 3000	
Variable 5: % Elongation		Variable 5: % Elongation	
Cases 1 through 10		Cases 81 through 90	
Mean:	3.810	Mean:	3.135
Variance:	0.870	Variance:	0.354
Standard Deviation:	0.933	Standard Deviation:	0.595

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.4595
Numerator degrees of freedom:	9
Denominator degrees of freedom:	9
Probability:	0.1962

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.6122
Variance of the difference between the means:	0.1224
Standard Deviation of the difference:	0.3499
t Value:	1.9291
Degrees of freedom:	18
Probability of t:	0.0696

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.675 plus or minus 0.735 (-0.060 through 1.410)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: BATCH 1		SAMPLE TWO: BATCH 2	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 126		Cases 127 through 252	
Mean:	44.246	Mean:	45.116
Variance:	47.217	Variance:	45.849
Standard Deviation:	6.871	Standard Deviation:	6.771

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.0298
Numerator degrees of freedom:	125
Denominator degrees of freedom:	125
Probability:	0.8697

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	46.5330
Variance of the difference between the means:	0.7386
Standard Deviation of the difference:	0.8594
t Value:	-1.0123
Degrees of freedom:	250
Probability of t:	0.3124

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.870 plus or minus 1.693 (-0.823 through 2.563)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% MAPP	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 29 through 56	
Mean:	52.521	Mean:	47.829
Variance:	58.468	Variance:	26.479
Standard Deviation:	7.646	Standard Deviation:	5.146

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.2081
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.0441

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	3.0338
Standard Deviation of the difference:	1.7418
t Value:	2.6936
Effective degrees of freedom:	47
Probability of t:	0.0094

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 4.692 plus or minus 3.504 (1.188 through 8.196)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% MAPP	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 57 through 84	
Mean:	52.521	Mean:	45.104
Variance:	58.468	Variance:	22.747
Standard Deviation:	7.646	Standard Deviation:	4.769

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.5703
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.0170

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	2.9005
Standard Deviation of the difference:	1.7031
t Value:	4.3548
Effective degrees of freedom:	45
Probability of t:	0.0001

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 7.417 plus or minus 3.430 (3.986 through 10.847)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% MAPP	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 85 through 112	
Mean:	52.521	Mean:	45.688
Variance:	58.468	Variance:	35.489
Standard Deviation:	7.646	Standard Deviation:	5.957

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.6475
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.2010

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	46.9782
Variance of the difference between the means:	3.3556
Standard Deviation of the difference:	1.8318
t Value:	3.7299
Degrees of freedom:	54
Probability of t:	0.0005

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 6.833 plus or minus 3.673 (3.160 through 10.505)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% SURLYN	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 113 through 140	
Mean:	52.521	Mean:	42.974
Variance:	58.468	Variance:	36.846
Standard Deviation:	7.646	Standard Deviation:	6.070

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.5868
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.2367

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	47.6570
Variance of the difference between the means:	3.4041
Standard Deviation of the difference:	1.8450
t Value:	5.1746
Degrees of freedom:	54
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 9.547 plus or minus 3.699 (5.848 through 13.246)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% SURLYN	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 141 through 168	
Mean:	52.521	Mean:	42.610
Variance:	58.468	Variance:	31.432
Standard Deviation:	7.646	Standard Deviation:	5.606

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.8601
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.1129

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	44.9500
Variance of the difference between the means:	3.2107
Standard Deviation of the difference:	1.7918
t Value:	5.5313
Degrees of freedom:	54
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 9.911 plus or minus 3.592 (6.319 through 13.504)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% SURLYN	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 169 through 196	
Mean:	52.521	Mean:	42.606
Variance:	58.468	Variance:	25.088
Standard Deviation:	7.646	Standard Deviation:	5.009

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.3305
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.0318

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	2.9841
Standard Deviation of the difference:	1.7275
t Value:	5.7397
Effective degrees of freedom:	46
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 9.915 plus or minus 3.477 (6.438 through 13.392)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 1000	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 197 through 224	
Mean:	52.521	Mean:	39.956
Variance:	58.468	Variance:	33.109
Standard Deviation:	7.646	Standard Deviation:	5.754

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.7659
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.1459

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	45.7881
Variance of the difference between the means:	3.2706
Standard Deviation of the difference:	1.8085
t Value:	6.9478
Degrees of freedom:	54
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 12.565 plus or minus 3.626 (8.939 through 16.191)

Title: IZOD IMPACT STRENGTH

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 3000	
Variable 5: Impact Strength		Variable 5: Impact Strength	
Cases 1 through 28		Cases 225 through 252	
Mean:	52.521	Mean:	42.840
Variance:	58.468	Variance:	49.107
Standard Deviation:	7.646	Standard Deviation:	7.008

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.1906
Numerator degrees of freedom:	27
Denominator degrees of freedom:	27
Probability:	0.6536

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	53.7873
Variance of the difference between the means:	3.8420
Standard Deviation of the difference:	1.9601
t Value:	4.9389
Degrees of freedom:	54
Probability of t:	0.0000

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 9.681 plus or minus 3.930 (5.751 through 13.610)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: BATCH 1		SAMPLE TWO: BATCH 2	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 27		Cases 28 through 54	
Mean:	1.830	Mean:	1.877
Variance:	0.534	Variance:	0.406
Standard Deviation:	0.731	Standard Deviation:	0.637

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.3177
Numerator degrees of freedom:	26
Denominator degrees of freedom:	26
Probability:	0.4867

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.4700
Variance of the difference between the means:	0.0348
Standard Deviation of the difference:	0.1866
t Value:	-0.2521
Degrees of freedom:	52
Probability of t:	0.8020

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.047 plus or minus 0.374 (-0.327 through 0.421)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% MAPP	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 7 through 12	
Mean:	2.107	Mean:	1.272
Variance:	0.255	Variance:	0.121
Standard Deviation:	0.505	Standard Deviation:	0.347

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.1144
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.4307

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1878
Variance of the difference between the means:	0.0626
Standard Deviation of the difference:	0.2502
t Value:	3.3377
Degrees of freedom:	10
Probability of t:	0.0075

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.835 plus or minus 0.557 (0.278 through 1.392)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% MAPP	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 13 through 18	
Mean:	2.107	Mean:	1.015
Variance:	0.255	Variance:	0.013
Standard Deviation:	0.505	Standard Deviation:	0.112

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	20.1858
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.0050

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	0.0446
Standard Deviation of the difference:	0.2112
t Value:	5.1694
Effective degrees of freedom:	5
Probability of t:	0.0004

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 1.092 plus or minus 0.543 (0.549 through 1.635)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% MAPP	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 19 through 24	
Mean:	2.107	Mean:	1.222
Variance:	0.255	Variance:	0.020
Standard Deviation:	0.505	Standard Deviation:	0.141

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	12.8653
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.0140

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	0.0458
Standard Deviation of the difference:	0.2140
t Value:	4.1356
Effective degrees of freedom:	5
Probability of t:	0.0020

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.885 plus or minus 0.550 (0.335 through 1.435)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 1% SURLYN	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 25 through 30	
Mean:	2.107	Mean:	2.162
Variance:	0.255	Variance:	0.041
Standard Deviation:	0.505	Standard Deviation:	0.202

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	6.2278
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.0662

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1479
Variance of the difference between the means:	0.0493
Standard Deviation of the difference:	0.2221
t Value:	-0.2477
Degrees of freedom:	10
Probability of t:	0.8094

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.055 plus or minus 0.495 (-0.440 through 0.550)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 3% SURLYN	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 31 through 36	
Mean:	2.107	Mean:	2.310
Variance:	0.255	Variance:	0.105
Standard Deviation:	0.505	Standard Deviation:	0.324

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	2.4355
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.3509

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1798
Variance of the difference between the means:	0.0599
Standard Deviation of the difference:	0.2448
t Value:	-0.8305
Degrees of freedom:	10
Probability of t:	0.4256

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.203 plus or minus 0.545 (-0.342 through 0.749)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% SURLYN	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 37 through 42	
Mean:	2.107	Mean:	2.910
Variance:	0.255	Variance:	0.073
Standard Deviation:	0.505	Standard Deviation:	0.269

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	3.5136
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.1941

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.1638
Variance of the difference between the means:	0.0546
Standard Deviation of the difference:	0.2336
t Value:	-3.4384
Degrees of freedom:	10
Probability of t:	0.0063

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.803 plus or minus 0.521 (0.283 through 1.324)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 1000	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 43 through 48	
Mean:	2.107	Mean:	1.422
Variance:	0.255	Variance:	0.308
Standard Deviation:	0.505	Standard Deviation:	0.555

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	1.2071
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.8414

Result: Non-Significant F - Accept the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Pooled s squared:	0.2813
Variance of the difference between the means:	0.0938
Standard Deviation of the difference:	0.3062
t Value:	2.2368
Degrees of freedom:	10
Probability of t:	0.0493

Result: Significant t - Reject the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.685 plus or minus 0.682 (0.003 through 1.367)

Title: WATER ABSORPTION

Function: T-TEST

SAMPLE ONE: 60% HDPE		SAMPLE TWO: 5% PROFLOW 3000	
Variable 5: Water Absorption		Variable 5: Water Absorption	
Cases 1 through 6		Cases 49 through 54	
Mean:	2.107	Mean:	2.260
Variance:	0.255	Variance:	0.029
Standard Deviation:	0.505	Standard Deviation:	0.171

F-TEST FOR THE HYPOTHESIS "VARIANCE 1 = VARIANCE 2"

F Value:	8.7671
Numerator degrees of freedom:	5
Denominator degrees of freedom:	5
Probability:	0.0325

Result: Significant F - Reject the Hypothesis

T-TEST FOR THE HYPOTHESIS "MEAN 1 = MEAN 2"

Variance of the difference between the means:	0.0473
Standard Deviation of the difference:	0.2176
t Value:	-0.7047
Effective degrees of freedom:	6
Probability of t:	0.4971

Result: Non-Significant t - Accept the Hypothesis
Confidence limits for the difference of the means (for alpha =0.05): 0.153 plus or minus 0.532 (-0.379 through 0.686)

APPENDIX D

APPENDIX D

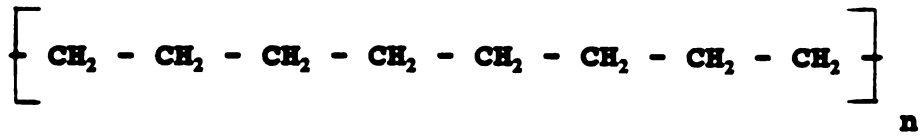


Figure 7. Chemical Structure of HDPE

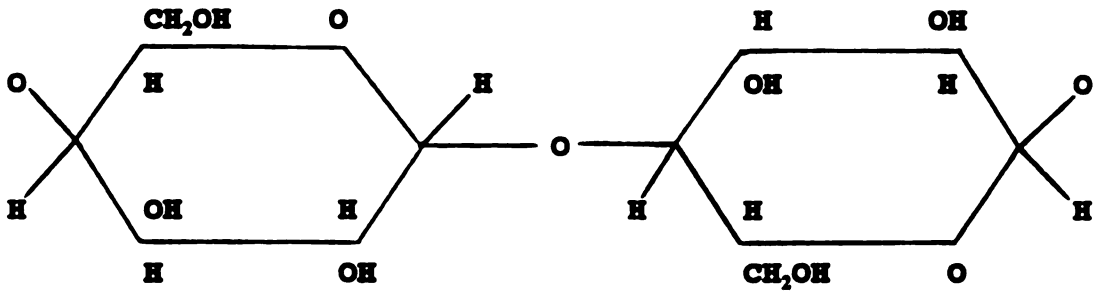


Figure 8. Chemical Structure of Aspen Hardwood Fibers

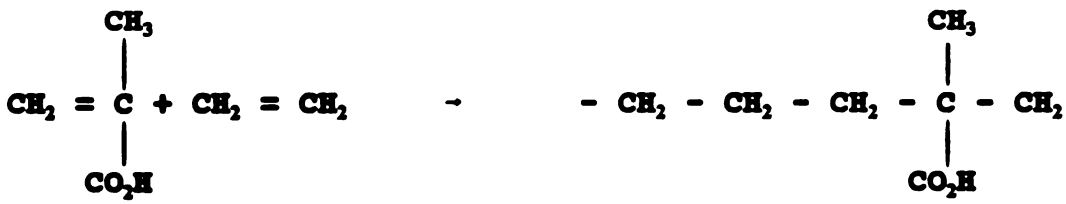


Figure 9. Chemical Structure of Surlyn

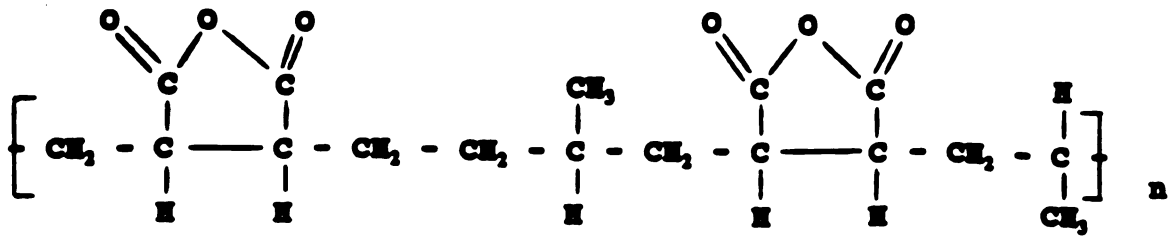
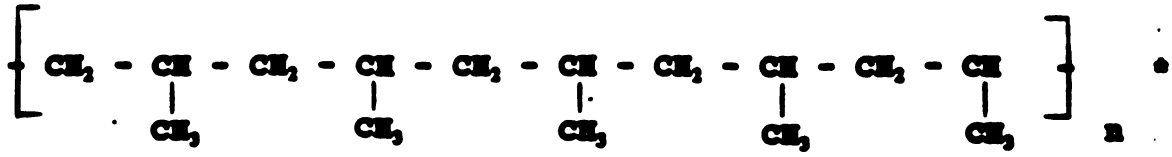


Figure 10. Chemical Structure of MAPP



*Proflow 1000 is a polypropylene homopolymer which is the structure you see above, while Proflow 3000 is a conventional ethylene/propylene copolymer.

Figure 11. Chemical Structure of Proflow Resins

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REFERENCES

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