Composite of Recycled High Density Polyethylene and Recycled Tire Particles by Compression Molding

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Key Words:
Recycled plastics, high density polyethylene (HDPE), recycled rubber, composites, compression molding, design of experiment (DOE).

Prerequisite Knowledge:
Behavior and processing of thermoplastics and rubber, compression molding of plastics, thermoplastic elastomers, design of experiments.

Objective:
To introduce students to compression molding of composite from recycled high density polyethylene (HDPE) and recycled automobile tire particles. To optimize the process parameters using design of experiments (DOE) techniques.

Equipment:
1. Compression molding machine (A metallurgical specimen press can be good enough.)
2. Compression molds
3. Cutoff wheel or other cutting tools

Introduction:
Plastic and rubber recycling is an effective means of reducing solid waste to the environment and preserving natural resources. A project aimed at developing a new composite material from recycled high density polyethylene (HDPE) and recycled rubber is currently being conducted at Eastern Illinois University. The recycled plastic pellets with recycled rubber particles are extruded into some HDPE/rubber composite strands. The strand can be further cut into pellets that can be used to fabricate other material forms or products.

This experiment was inspired by the above-mentioned research activity. In order to measure Durometer hardness of the extruded composite, a specimen with relatively large dimensions was needed. Thus, compression molding was used to form a cylindrical specimen of 1” diameter and 1” thickness. The initial poor quality of the molded specimen prompted a need to optimize the processing parameters such as temperature, holding time and pressure. Design of experiment (DOE) was used to obtain optimum combination of the parameters.

Experiment:
The composite of 95%HDPE - 5%rubber was pelletized into small particles before being used for

compression molding. A metallurgical specimen press was used as a compression molder for making a composite cylindrical block of 1” diameter and 1” thickness. To improve the quality of molded specimen, parameters such as holding time (min.), temperature (“C), and pressure (psi) are identified as controllable variables to be optimized. Heating rate, environment, quality of composite pellets and distribution of rubber in pellets are identified as uncontrolled variables.

A two level full factorial (2^3) design was used for the experiment. Appropriate levels of the controllable variables are determined by fundamental understanding of materials properties, practical knowledge and limits of the press. For example, a heating temperature was chosen between 130 and 150 “C, holding time at the experimental temperature would not exceed twenty minutes, and highest pressure and temperature that can be obtained in the apparatus are 10,000 psi and 150 ºC respectively. The design matrix (coded test conditions), actual test condition matrix and experimental results are shown in Table I.

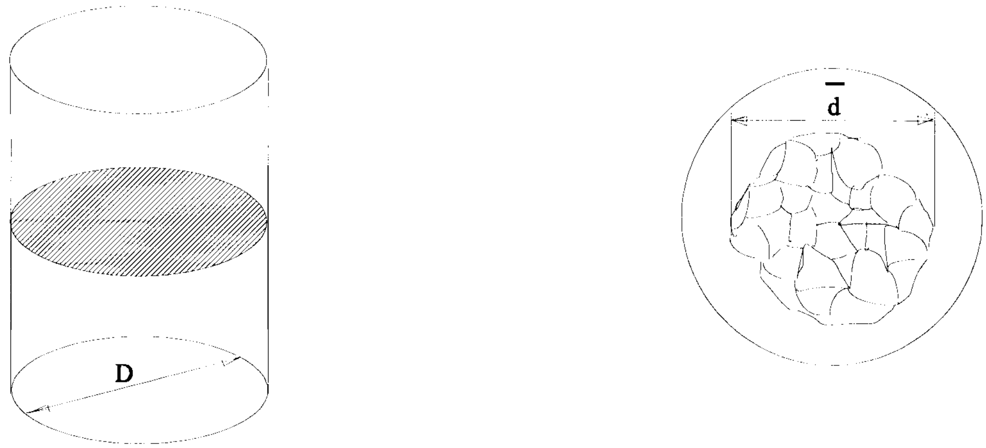
Table I. Coded test conditions, actual test conditions and results of compression molding

Coded Test Conditions				Actual Test Conditions				Results	
Test	x,	x*	x_3	Test Order	Time (min)	Temperature (ºC)	Pressure (psi)	Formability	Appearance
1	-	-		6	5	130	2000	22%	Fair
2	+	-	-	8	15	130	2000	25%	Good
3	-	+	-	1	5	150	2000	54.5%	Excellent
4	+	+	-	2	15	150	2000	100%	Excellent
5	-	-	+	5	5	130	6000	10%	Bad
6	+	-	+	3	15	130	6000	25.5%	Good
7	-	+	+	4	5	150	6000	42%	Excellent
8	+	+	+	7	15	150	6000	100%	Excellent

Before tests, a random testing order was determined, as listed in Table I. Nine grams of HDPE/rubber composite pellets were used for the molding. Pressure was maintained at the designed level during the whole period of processing. After temperature reached the set value, the holding time was counted. When holding time was up, pressure was released, electrical power for heating was turned off. All eight samples were made in the same procedure.

The surface appearances of samples were first examined with naked eyes. Four qualitative scales were used to describe the surface quality of the specimen, *i.e.*, excellent, good, fair and bad. Then, samples were cut in the middle of height, as shown in Fig. 1 (a). Formability was defined as a percentage of melted diameter in cross-section in relation to the diameter of the specimen, which is calculated according to the following equation.

$$Formability = [1 - \frac{Average\ Unmelted\ Diameter\ (\bar{d})}{Diameter\ of\ Sample\ (D)}] \times 100\%$$



(a) (b)

Figure 1. Schematic of compression-molded specimen: (a) Cross-section position in the specimen, (b) average unmelted diameter $\bar{d}$.

Results and Analysis:

The experimental results are shown in right columns of Table I. Surface appearance was used to evaluate the quality of specimens before cross-sectioning was made. The experimental results could be rearranged according to the level of surface quality of specimens, as shown in Table II. It is noted that the surface appearance was excellent when temperature was 150 °C regardless of holding time and pressure. At low temperature level, the surface quality of specimen was good when holding time was 15 min. When a shorter holding time were chosen, the surface quality was fair at lower pressure and bad at high pressure level. In other words, temperature is a significant factor in the compression molding.

For the formability, the data analysis is presented in Table III. Among the three factors, temperature showed the largest effect on the formability, which increased formability from 20.625°/0 at lower level to 74.1259’0 at higher level, *i.e.,* a net increase of 53 .5%. The second effective factor was time, showing 30.5% net increase from lower level to higher level. Pressure showed a negative effect on the formability, which is consistent with the thermodynamic principle that the melting point of a substance will increase with increasing pressure. Moreover, pressure had the least effect on the formability in the testing range among the three factors.

The interaction between time and temperature was very strong. That implies that the two factors have to be controlled synergetically to optimize the compression molding quality. There was less significant interaction between holding time and pressure, which can be neglected for practical purpose. There was no significant interaction between temperature and pressure

In summary, a good compression specimen can be obtained using a higher temperature (150 ‘C), a longer holding time (15 min.) and a lower pressure (2000 psi).

Table II. Rearrangement of actual test conditions and the results

Test Order	Time (rein)	Temperature (°C)	Pressure (psi)	Result	
				Appearance	Formability
5	5	130	6000	Bad	10%
6	5	130	2000	Fair	22%
8	15	130	2000	Good	25%
3	*15*	130	6000	Good	25.5%
4	5	150	6000	Excellent	42'%
1	5	150	2000	Excellent	54.5%
2	15	150	2000	Excellent	1 00%
7	*15*	*150*	*6000*	Excellent	100'XO

Table III Main effects and interactions of factors

Test	Main Effects			Interactions				Formability
	Time x_1	Temp. x_2	Press. X_3	x,x*	x_2x_3	X,X,	$x_1x_2x_3$	
1	-1	-1	-1	+1	+1	+1	-1	22%
2	+1	-1	-1	-1	+1	-1	+1	25%
3	-1	+1	-1	-1	-1	+1	+1	54.5'%
4	+1	+1	-1	+1	-1	-1	-1	1 00%
5	-1	-1	+1	+1	-1	-1	+1	1 o%
6	+1	-1	+1	-1	-1	+1	-1	25.5%
7	-1	+1	+1	-1	+1	-1	-1	42%
8	+1	+1	+1	+1	+1	+1	+1	100'%0
Sum +	250.5	296.5	177.5	232	189	202	189.5	
Sum -	128.5	82.5	201.5	147	190	177	189.5	
E_i	30.5'%0	53.5%	-6%	21.25'%	-0.25%	6.25'%	o%	47.375% (Average)

Conclusions:

The following conclusions can be made from the analysis of 2^3 factorial experiments.

(1) HDPE/rubber composite pellets can be compression-molded as a thermoplastic elastomer. The experiment can be performed by a simple metallurgical specimen press if a compression molding machine is not available.

(2) In compression molding, temperature is the most significant factor to control so that a good surface quality can be achieved.

(3) The interaction between time and temperature is very strong. Other interactions can be neglected for practical purpose.

(4) The optimum parameters for the compression molding of the HDPE/rubber composite are higher temperature (150 'C), longer holding time (15 min.) and lower pressure (2000 psi).

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