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Evaluation of the mechanical behaviour to the force of tension between thermoplastic materials of origin and recycled

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Abstract. The use of plastic products and polymeric matrix compounds is increasing in engineering, most of these materials are subjected to dynamic loads, therefore, are constantly evaluated according to experimental methods that allow a characterization of their main properties. Therefore, this research work consisted in carrying out the characterization of mechanical properties of thermoplastic materials of different origin; commercial and recycled, where three cases were worked: Polymethylmethacrylate, polyvinyl chloride and polypropylene, for which there were 3.5 ± 0.1 mm thick sheets, manufactured by extrusion and supplied by a local supplier, in the city of San José de Cúcuta, Colombia. Afterwards, the specimens or samples were cut for the tension test adapting the shape and geometry, according to the standard test method for tensile properties of plastics, ASTM D638-14, using laser cutting for such purpose, the specimens were conditioned at a temperature of 20 °C during 40 hours prior to the moment of the tension test, the equipment used was a universal machine branded from Electro Mechanical Instrument & Components Corp., commercial reference DL2000 N° 11760 NS 784 with a speed adjustment of 5 mm/min to keep within the times given by the standard. Once the tests are performed, the stress/strain graphs of each case studied are obtained and the experimental results are analyzed from the data provided by the software "Tesc versão 4.00". Afterwards, Young's module is statistically analyzed and compared in each study, seeing which one presents the best behavior under the studied load conditions, raising a hypothesis, where the question is if the differences in the sample between Young's module can come from a population with an mean of zero, in this case, it is concluded that there is no difference between Young's modulus values for polymethylmethacrylate samples, the same occurred for polyvinyl chloride and polypropylene.

1. Introduction

Most of the materials used in engineering are subject to dynamic loads, which is why we are promoting the development of reliable experimental methods that allow the characterization of the mechanical behavior of materials and their fracture processes under low, medium and high-speed conditions. The use of plastic products and polymeric matrix compounds is increasing in engineering, so that at this time it is so necessary to study their properties as the development of test methods to characterize them under different conditions of load application, being of particular interest to know the response of them to high speeds of load [1].

Therefore, nowadays, for economic reasons, the industry is looking for materials that are more competent in terms of resistance and that at the same time have a low weight. By way of example, and to illustrate the importance of this, it is the case of the aeronautics industry, which is looking to change materials such as steel, which is high in strength and high in density, for a composite material, often carbon and epoxy, which is high in strength but low in density. A low density of the ship's parts means that there is less weight to move, so there is less kerosene consumed and therefore a saving of money [2-5]. In the search for a better use of the resources that nature offers and its use to solve material engineering problems for humanity, thermoplastic polymers are considered a potential alternative, because these materials have a very particular characteristic compared to other families of polymers, and that is that they can be reprocessed, that is, they can be subjected to several manufacturing processes [6]. Plastics, due to their composition and their origin derived from petroleum, that is to say, from an exhaustible raw material, are a high value waste, relatively easy to recover and process, and are found in the environment in abundance, much more so than glass in domestic waste and growing among industrial waste. Therefore, plastics are subject to selective collection in cities where there are companies that recover or process this type of material. However, despite being materials with properties for recovery, they present a low level of recovery in different industrial sectors [7].

For the manufacture of good performance parts for applications in mechanical devices (gears, technical parts for the electrical and automotive industries, among others), it is required that the polymer presents high mechanical resistance (rigidity), good toughness and excellent dimensional stability [8]. The most used materials for these applications are: polyamides (nylon in general), thermoplastic polyesters, such as polyethylene terephthalate (PET) or polycarbonate (PC) or styrene-butadiene-acrylonitrile copolymers (ABS), among others [9,10]. Therefore, the study of the creep behavior of a material is a fundamental step to establish reliability limits in engineering design [11]. At industrial level, it is of great interest to know the response of a component under a load, in the short and long term. The properties to characterize the short-term response are obtained through traction and impact tests, while those corresponding to the long-term response are found using relaxation and dynamic tests [12]. According to the above mentioned, tensile test is the most used to know many mechanical properties of materials, such as strength, elasticity and ductility characteristics, among others [13]. The results obtained from tests allow to establish: safety, protection in case of responsibility, quality control, establish standards and specifications, evaluate competitor products and establish strategies to improve the qualities of materials based on the application [14].

The present research work aims to carry out an evaluation of the mechanical behavior at tensile strength of regular commercial plastic specimens and recycled plastic of polymethylmethacrylate (PMMA), polypropylene (PP) and polyvinyl chloride (PVC), and according to the methodology given in section 2. In section 3 and 4, the experimental results of performing tensile tests on the first specimens of each of the materials are presented, at the same time the stress and strain curve is presented, respectively, posing a hypothesis where the question is whether the differences in the sample between Young's modulus can come from a population with a mean of zero (0), in which case, it is concluded that there is no difference between the values of Young's modulus. It ends with section 5, with conclusions and a final perspective contribution.

2. Methodology

For the present work of investigation an experimental methodology was approached, because for the development of the investigation tests of the materials were realized of which they gave a few results for his later analysis. That is, an object of study was taken and subjected to certain environmental conditions to observe its results, in order to reach some conclusions about the effect produced by the environmental conditions on the object of study [15].

2.1. Material used

PMMA sheets with a thickness of 3.5 ± 0.1 mm, were used. This material has great mechanical resistance, high Young's modulus and low elongation at break. It is a thermoplastic linear polymer, presents methyl groups on its carbon chain, is one of the hardest thermoplastics and also more resistant to scratches, shows low moisture absorption, because the products manufactured have a good dimensional stability [1].

For the case of PP, a film with a thickness of 3.5 ± 0.1 mm, was used. This material has a medium level of crystallinity between that of low-density polyethylene (LDPE) and high-density polyethylene (HDPE), although it is less hard than HDPE and less flexible than LDPE, it is much more fragile than HDPE. Its behavior to traction depends on the speed of load and temperature, the lower the speed of traction, the higher the value of mechanical characteristics, its Young's modulus is intermediate between that of LDPE and HDPE [16].

In the case of PVC, a sheet with the same dimensions as the previous ones was used. This material is considered a homopolymer, a semi-crystalline polymer with relative resistance to high temperature, depending on the formulation or composition, its Young's modulus can be lowered by plasticizing entities to produce semi-rigid and flexible articles. Many of these have proven to be commercially useful and cost competitive. The use of other additives, besides plasticizers, is essential to make flexible PVC. These include stabilizers, pigments, fillers, lubricants and many other specialties, such as flame retardants, antimicrobials, antistatic with particular applications, among others [17,18]. The above materials were manufactured by extrusion and supplied by a local company, located in the city of San José de Cúcuta, Colombia.

2.2. *Construction of the specimens*

From the supplied material sheets, three (3) of regular commercial type and three (3) made from recycled plastic, sixty (60) specimens or samples were cut for the stress test adapting the shape and geometry, according to ASTM D638-14 [19], using laser cutting for that purpose. Figure 1, presents an outline with the dimensions of the specimens used, where the design was used the type IV specimen of the ASTM D638-14 standard [19], where the overall length (OL) = 115 mm, the overall width (OW) = 19 mm and the width of narrow section (W) = 6 mm.

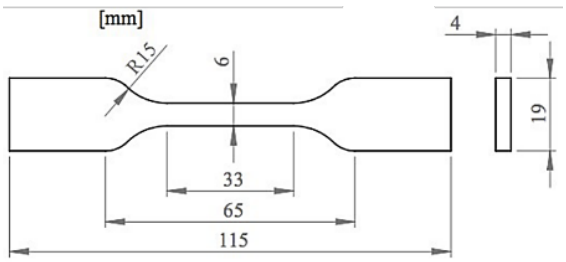

Figure 1. Diagram of the specimens used for the tensile test according to ASTM D638-14.

The specimens are distributed as follows: 10 commercial PMMA specimens, 10 recycled PMMA specimens, 10 commercial PVC specimens, 10 recycled PVC specimens, 10 commercial PP specimens, 10 recycled PP specimens. One of the main problems that occur when performing a test is the need to use a sample of the material for the construction of specimens, most of the times they are destructive, so the use of the specimen can only be used for one test [14]. The performance of a test sometimes involves the use of several specimens. Therefore, the specimens are extracted from main parts, for a production control with this method could be high in costs [14]. In this case of mass production, a random sample of material was taken, since the company develops this quality control mechanism.

Before carrying out the tests of characterization of the specimens, these are placed in a conditioning process, at a temperature of 20 °C, in order to reach an equilibrium in terms of relative humidity. This process of resting the specimens was carried out for 40 hours, prior to the time of the test.

2.3. *Traction device*

The tension test was performed in the material resistance laboratory, polymer section, of the Universidad Francisco de Paula Santander, located in the city of San José de Cúcuta, Colombia. It was performed at a temperature of 20 °C and a speed adjustment of 5 mm/min to keep within the times given by the standard. The equipment used was a universal machine of the supplier Electro Mechanical Instrument & Components Corp. (EMIC) reference DL2000 N° 11760 NS 784 from the multinational "Equipamentos e sistemas de ensaio Ltda". The assembly was made with the support of the laboratory assistant and the heads of the specimen were carefully adjusted, trying to avoid any kind of contamination or defect in the specimen. The following main characteristics have been determined experimentally by the equipment used: maximum force, maximum tension, tensile force, elongation breakage, elongation flow, modulus of elasticity. The device allows to determine the experimental results through the software "Tesc versão 4.00".

3. Results and discussion

From the report issued by the testing machine system, the following were obtained: maximum force, maximum tension, tensile force, elongation breakage, elongation flow, modulus of elasticity or Young's modulus. Table 1, presents the first observation for a commercial polypropylene (PP_1) and a recycled polypropylene (PP_{1R}) specimen, therefore, Table 1, shows the basic mechanical properties determined for this specimen in the tensile strength test; during the test, the variables stated for all the specimens were recorded continuously and simultaneously. Therefore, in Table 2, Young's modulus is presented in summary, for each of the observations of all the specimens, where the subscript "R" represents recycling.

Table 1. Basic maximum mechanical properties of PP1 and PP1R specimens.

	Maximum force (N)		Maximum stress (Mpa)		Tensile stress (Mpa)		Elongation rate (%)		Modulus of elasticity at 2% (MPa)	
Test specimen number	PP_1	PP_{1R}	PP_1	PP_{1R}	PP_1	PP_{1R}	PP_1	PP_{1R}	PP_1	PP_{1R}
Core values	566.77	508.69	14.53	13.04	7.62	5.91	1.620	0.890	1099.00	1238.9
Mean	566.80	508.70	14.53	13.04	7.62	5.91	1.616	0.891	1099.00	1239.0
Median	566.80	508.70	14.53	13.04	7.62	5.91	1.616	0.891	1099.00	1239.0
Minimum	566.80	508.70	14.53	13.04	7.62	5.91	1.616	0.891	1099.00	1239.0
Maximum	566.80	508.70	14.53	13.04	7.62	5.91	1.616	0.891	1099.00	1239.0

The stress-strain distributions for the first observation of PP_1 and the stress-strain distribution for the first observation of PP_{1R} is shown in Figure 2, these figures are only to illustrate the behavior of the materials, where it is evident that the stress-strain curve obtained resembles that of a conventional thermoplastic polymer material. That said, presenting all the figures of the totality of the observations would imply consumption of space within the manuscript; therefore, the main variable is summarized in Table 2, for later analysis.

According to Figure 2, the first observation of PP_1, it has that, the test piece presented a considerable stretch in its zone, with an average time of test of 487.83 seconds or 8.10 minutes, presented a Young's modulus in average of 1,099.00 MPa supporting a tensile force of 14.53 MPa, resulting in a material with ductility properties. In the distributions presented in Figure 2, Young's modulus is calculated as the slope between two points of the line or the line tangent to the curve, these points are automatically generated by the software of the tensile testing machine. According to Figure 2, for the first observation of PP_{1R}, it presented a stretch in its central area, with an average test time of 588.66 seconds or 9.80 minutes, it presented a Young's modulus of 1238.93 MPa supporting a tensile force of 13.04 MPa, the material is ductile and did not reach breakage.

For the present study, a hypothesis test was carried out about the difference in the population mean between paired or dependent observations. It is desired to study the similarities of modulus of elasticity of polymeric materials (PMMA, PVC and PP), for which a sample is selected, the standard stress tests are performed, to the material that presents two types of origin according to its manufacture, being these: commercial and recycled. In other words, the relationship presented is one of comparison of the variable (modulus of elasticity) of different processing origins of the same material.

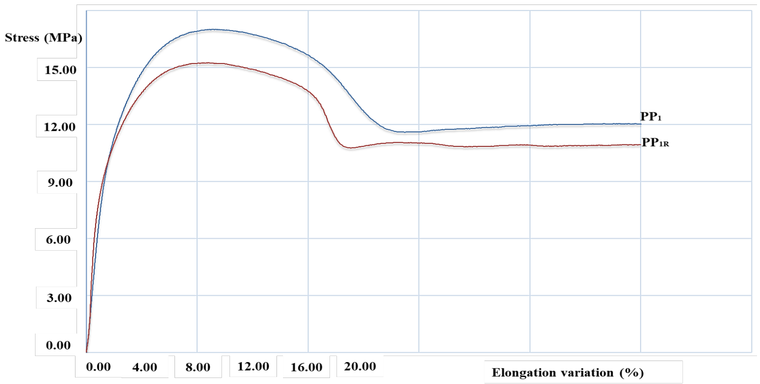

Figure 2. Stress – strain distribution of specimen PP_1 and PP_{1R}.

It is desired to compare the two types of origin (commercial and recycled) by calculating their modulus of elasticity or Young's modulus. For this purpose, a sample of 10 specimens or test pieces of both types of processing was selected, and the results are shown in Table 2.

Table 2. Young's module of the different materials according to their processing of origin.

Observation	Elasticity modulus					
	PMMA	$PMMA_R$	PVC	PVC_R	PP	PP_R
1	3020.00	2750.00	2983.64	3701.06	1099.00	1238.93
2	3592.00	2392.00	3396.00	2490.00	1375.00	1108.00
3	2742.00	2879.00	2384.00	3016.00	1298.00	1188.00
4	3058.00	3109.00	4089.00	3025.00	1185.00	1105.00
5	3184.00	3068.00	3012.00	2702.00	939.00	1179.00
6	3642.00	2559.00	2206.00	2888.00	958.00	1177.00
7	2547.00	2648.00	3471.00	3569.00	914.00	1112.00
8	3265.00	2851.00	2639.00	3371.00	994.00	1138.00
9	3314.00	2880.00	4090.00	2615.00	1361.00	1107.00
10	2894.00	3317.00	3542.00	2992.00	1212.00	1126.00

We proceed to raise the null and alternative hypothesis; in this case a two-tailed alternative is appropriate because we want to determine if there is a difference between Young's modules of the two origins (commercial and recycling). The question is whether the differences in the sample between Young's modules can come from a population with a mean of zero (0); in that case, it would be concluded that there is no difference between Young's modules. The null and alternative hypotheses are: H_0: $\mu_1 = 0$ y H_1: $\mu_1 \neq 0$. Since 10 observations were made for both types of processing (commercial and recycling), so n = 10, and gl = n - 1 = 9. A two-tailed test, and the significance level is 0.05, the critical value is determined according to the t student-distribution, which is 2.262. Therefore, the decision rule is to reject the null hypothesis if the calculated value of t is less than -2.262 or greater than 2.262.

According to the above, Microsoft Excel ® software was used the procedure "Student's t-test for means of two paired samples", to determine the values of the t statistic, in the samples. In the case of PMMA and $PMMA_R$, the calculated value of t is not in the region of rejection, therefore, the null hypothesis is accepted. In other words, the distribution of the differences of the population has a mean of zero, therefore, it is concluded that, there is not a different one between the mean Young's modules of PMMA and $PMMA_R$ material. For the case of PVC and PVC_R, the calculated value of t is 0.548, and the two-tailed p value is 0.597. Since the p value is larger than 0.05, the hypothesis that the mean of the difference distribution between Young's modules is zero is accepted. For the case of PP and PP_R, the calculated value of t is -0.233, and the two-tailed value of p is 0.821. Since the value of p is larger than 0.05, and the value of t is not in the rejection region, it is accepted the hypothesis that the mean of the distribution of differences between Young's modules is zero.

Table 3. Test t for paired two-sample mean.

	Elasticity modulus					
	PMMA	$PMMA_R$	PVC	PVC_R	PP	PP_R
Mean	3125.800	2845.300	3181.264	3036.906	1133.500	1147.893
Variance	121535.733	75496.011	428722.253	161098.288	31490.500	2075.572
Observations	10.000	10.000	10.000	10.000	10.000	10.000
Pearson's correlation coefficient	-0.411		-0.198		-0.293	
Hypothetical difference of the means	0.000		0.000		0.000	
Degrees of freedom	9.000		9.000		9.000	
Statistical t	1.689		0.548		-0.233	
P (T ≤ t) a tailed	0.063		0.298		0.411	
Critical value of t (one-tailed)	1.833		1.833		1.833	
P (T ≤ t) two tailed	0.126		0.597		0.821	
Critical value of t (two-tailed)	2.262		2.262		2.262	

4. Conclusions

In this study three types of materials were analyzed, each one faced its homologous that came from a different origin not so pure, i.e., recycled, the specimens of PMMA and $PMMA_R$, PVC and PCV_R, PP and PP_R, showed from the statistical study and the hypothesis raised that the distribution of the differences of the population has an mean of zero, i.e., that there is no significant difference between the mean Young's modulus between the main material and its counterpart, this connotes that, recycled thermoplastic materials, present mechanical characteristics similar to those of pure origin, due to their reprocessing properties, which makes them candidates for different engineering applications of lesser demand. However, for future studies, the number of reprocessing, the type of cut of the specimens and the way of being manufactured should be considered.

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