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Recycling of Acrylonitrile–Butadiene–Styrene Using Injection Moulding Machine

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Abstract

ABS (Acrylonitrile Butadiene Styrene) is a thermoplastic resin commonly used for injection moulding applications. The effects of the recycling of ABS on mechanical properties were assessed. In this study, ABS was investigated in an attempt to overcome some of the barriers that currently hinder the progress of recycling activities. A recycling process was simulated in order to study the effects of recycling on mechanical properties of pure ABS with the injection moulding machine to create the specimens. Phase structure and mechanical properties of the ABS material were characterized by scanning digital microscope and tensile tests measurements. It was found that the effect of recycling on ABS is significant, in that change in tensile strengths and strains to failure were reduced considerably. Recycling of ABS caused no more deterioration in properties than occurred as a result of the first process.

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1. Introduction

As resources decrease and waste increases, recycling has thus become imperative, and a critical environmental

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practice [1]. Within this context, the political agenda of developed nations has been focused more and more on enabling households to reach sustainable waste management targets, thereby enhancing responsible waste behaviour, such as effective recycling. Engineers compare the relative effects of alternative technologies, and the impact of their mechanical properties on waste recycling systems [2].

Acrylonitrile–butadiene–styrene (ABS) is widely used in automotives, instrumentations, and industrial and domestic appliances due to its excellent mechanical properties, dimensional stability, and chemical resistance performances [3]. ABS consists of poly-butadiene (PB) particles dispersed and partially grafted in a styrene/acrylonitrile (SAN) continuous phase [4]. Different polymerization processes have been described elsewhere [5,6].

Even though ABS plastics are used largely for mechanical purposes, they also have good electrical properties that are fairly constant over a wide range of frequencies. These properties are little affected by temperature and atmospheric humidity in the acceptable operating range of temperatures. The final properties will be influenced to some extent by the conditions under which the material is processed to the final product; for example, moulding at a high temperature improves the gloss and heat resistance of the product whereas the highest impact resistance and strength are obtained by moulding at low temperature [7].

Thermoplastics can be melted and reused although the purity of the material tends to degrade with each reuse cycle. The products created with a thermoplastic have a number of amounts of used. Each number corresponds to the cycle the plastic has. This number can be used for an easy separated for the recycling.

The plastic injection moulding process produces large numbers of parts of high quality with great accuracy, very quickly. Plastic material in the form of granules is melted until soft enough to be injected under pressure to fill a plastic injection mould. The result is that the shape is exactly copied. Once the plastic moulding has cooled sufficiently to harden the mould opens releasing the part. The whole injection moulding process then repeats. The length of time from closing the mould to ejecting the finished plastic moulding is the cycle.

Consider the typical tensile specimen, the gage section is the important part of it. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The gage length is the region over which measurements are made and is centred within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter. Otherwise, the stress state will be more complex than simple tension [8].

2. Experimental details

2.1. Materials and equipment

A commercial ABS with MFI of 96 g/ 10 min (220 ºC, 10 kg) and specific weight of 1.04 g/cm3 was used as the polymeric material in present study. Arburg 270A 350-70 twin-screw extruder with 5.5 kg/h extruding capacity was used for melt compounding of the materials (Figure 1). Mechanical tests specimens were injected using an Arburg 270A 350-70 injection moulding machine with screw L/D ratio of 18, screw diameter of 24.5 mm and maximum injection pressure of 250 MPa. After the injection moulding cycle, the piece is not complete because there are excess materials along with any flash (Figures 2 and 3). This material must be trimmed from the piece. The excess material can be used again in the process but it need be recycled into a plastic grinder and mix with raw material.

A TestT tensile testing machine with maximum capacity of 112.5 KN and extension resolution of 1000 mm was used for performing tensile tests (Figure 1). The values were analyzed with the software TesTWinner 922.

a

b

Fig. 1. a) Mill machine b) Tensile test machine

Fig. 2. ABS before and after milling.

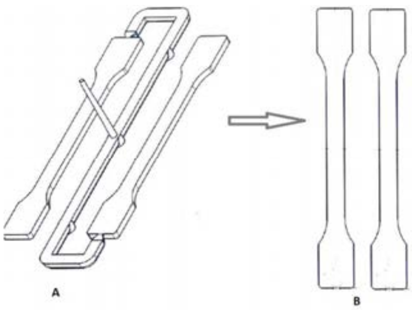


Fig. 3. Piece after Ejection (A). Final piece (B).

The VHX-1000 Digital Microscope with a built-in charge-coupled device (CCD) camera was used for the magnified viewing of samples and specimens. These microscopes can usually be connected to a computer so that the images they produce can be saved onto a hard drive for later inspection, or displayed on a monitor so that several people can see a specimen at the same time.

2.2. Preparation of specimens

Eight parameters are considered in the injection moulding machine. These parameters can be changed to calibrate the machine (Table 1) and they are the following:

- Volume: The correct volume determines the complete filling of the cavity. If the volume is too small, it incomplete filling the tool and if it is too much, it forms a heavy burr.
- Temperature: The correct temperature determines the complete melting of the plastics. If it is too small, it cannot enter inside the mould and if it is too high, maybe it can be burn. We have to select 5 temperatures because of the configuration of this injection moulding machine. The first four temperatures are from the heaters around the screw and their mission is melting the plastic material. The fifth temperature is for the part where the material is waiting to enter in the barrel and it is starting to heat.
- Injection rate: The current injection defines the volume per time that flows during the injection process into the tool.
- Injection pressure: Crucial for the rapid and complete filling of mould cavities. The viscous mass is injected in a very short time in the tool; therefore, the high injection pressure is up to 1800 bar.
- Pressure after injection: Although the emphasis begins only after the injection process, it contributes significantly to the quality of the moulded part. The reason is while the material is cooling inside the mould, it is smaller so we need inject more material for complete all the volume of the mould and if it is in not enough, we cannot do it.
- Back pressure: The pressure applied to the plastic during screw recovery. By increasing back pressure, mixing and plasticizing are improved; however, screw recovery rates are reduced.
- Volume of changing pressure: Defines the switching point of injection pressure to holing pressure by volume. In the software of the machine it corresponds to the order, the difference between switching on volume dosage system volume and volume of the injection moulded part.
- Time of pressure after injection: Is the time that we are going to wait while cooling.

After several tests, the more suitable parameters have been taken for this work (Table 1).

Table 1: Ideal parameters in injection moulding

Volume ($cm^{3)}$	31.5				
Temperature (ºC)	260	255	250	250	50
Injection Rate (cm^3/s)	35-25				
Injection Pressure (bar)	1200				
Pressure after Injection (bar)	550-450				
Back Pressure (bar)	50				
Volume of Changing Pressure (cm^3)	1.5				
Time of Pressure after Injection (s)	25				

In the first process 300 pieces were done and 50 pieces were selected from the 240 to 289. The rest of the material, pieces from 1 to 239 and from 290 to 300 and the plastic assembly were milled to use it in the second process. In the second process 230 pieces were done and from 160 to 209 were chosen. The rest were milled again. In the third process 160 pieces were done and from 90 to 139 were taken. The rest of the material was milled again. In the fourth process 120 pieces were done and from 60 to 110 were selected. The rest were kept.

2.3. Mechanical properties

To investigate the mechanical properties of materials, perhaps a tensile test is the most important fundamental test of a material's mechanical response [9]. One of the most important data's obtained from the tensile test is the ultimate tensile strength of the tested material. Tensile strength is the maximum tensile stress that a material can endure before it undergoes cracking, fracture or plastic deformation. In order to perform this test, first the specimens were injected into a cavity machined according to the ASTM: D638-10 standard [10]. Then tensile tests were carried out based on aforementioned standard at room temperature. At least three samples were examined for each trial and average tensile strength. Table 2 shows the main parameters of the material tested.

Table 2: Tensile test parameters

Test speed	30 mm/min
Sample cross section	40 mm^2
Total sample length	158 mm
Initial length	114 mm
Maximum strength	50 kN
Weg traverse	18 mm

3. Results and discussion

It can be observed after the tensile test that each specimen broke in three different zones that will all demonstrate different amounts of elongation and deformation until the specimen finally breaks (Figure 4).

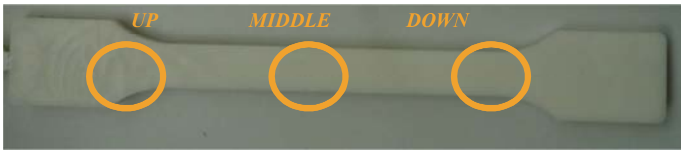


Fig. 4. ABS pictures locations.

3.1. Process I

The values obtained in this process are more representatives in their graphic form (Figure 5).

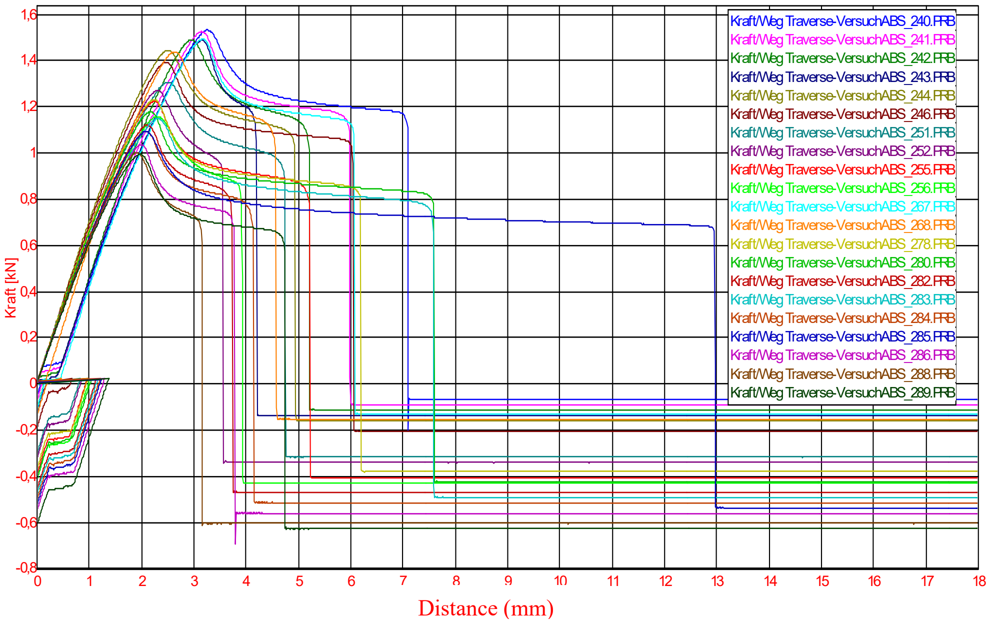


Fig. 5. ABS tensile test "middle breakage" results together.

3.2. Process IV

It can be observed after the tensile test that each specimen has break in a different zone. The values obtained in this process are more representatives in their graphic form (Figure 6).

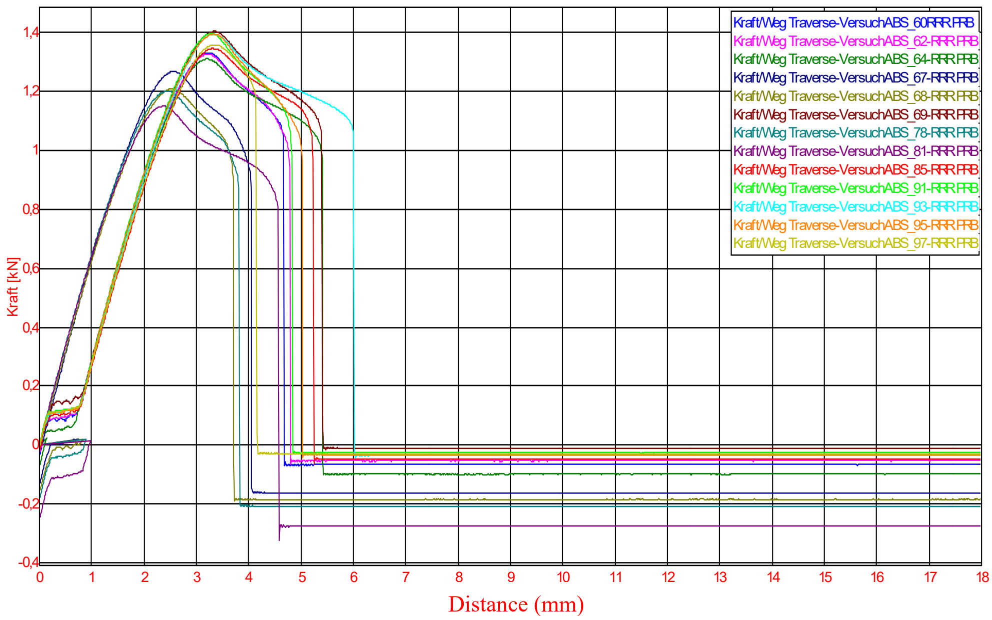


Fig. 6. ABS-RRR tensile test "middle breakage" results together.

The material in the four process show elastic response over a range of strain. As it can be observed on table 3, the values average of strength and tension can be divided in two groups. The first group is the process I and the process IV as the values of strength and tension are similar. The second group with the average of process II and process III has as well the average very similar. It can be said that the recycling material once and twice have better results of strength in the tensile test.

Table 3: Average of Strength and Tension

	Average of Strength and Tension			
	ABS	ABS-R	ABS-RR	ABS-RRR
Strength (kN)	1.290	1.437	1.442	1.304
Tension (N/mm^2)	32.258	35.758	36.540	32.622

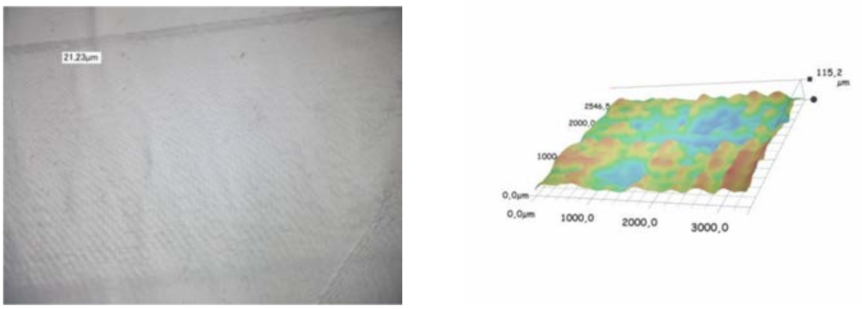
It can be observed that the values of average of break down distance, shown in the table 4, are bigger in the process II and process III, that means that the recycling material have more elasticity, they can absorb more strength. As we can see, the third recycling, ABS-RRR, have less distance than the other process I, II and III.

Table 4: Average of "break down" distance

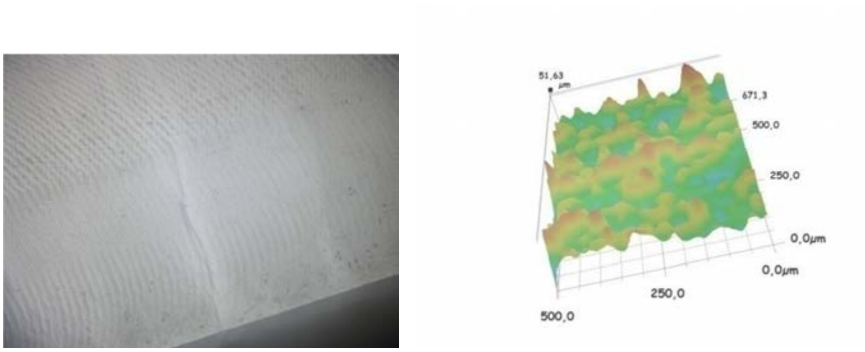
	Average of "break down" distance			
	ABS	ABS-R	ABS-RR	ABS-RRR
Distance (mm)	4-10	3.5-14	5-12	3.5-5.5

Figure 7 (a-d), shows the digital images for each process. All the pictures show a lot of differences between each process. The surface in the first process is smooth and looking at the others process we can observe that the surfaces are changing. The surface is more and more roughness only appreciates with the microscope.

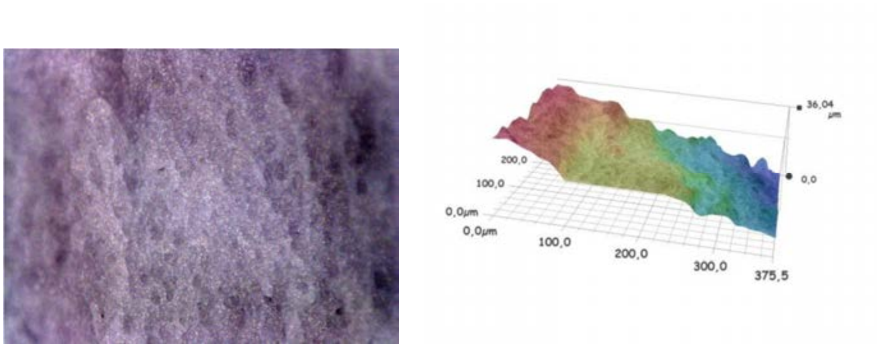
It can be appreciated as well, that the cutting surface, where the specimens have been broken are different. At the beginning, the cutting surface is smooth and has not irregularities. One on a time, the cutting surfaces is getting more irregularities and at last, in the fourth process, we can see without the microscope the irregularities and also small pieces of the specimens.



a) process I



b) process II



c) process III

d) process IV

Fig. 7. Digital 2D and 3D images of the specimens.

4. Conclusion

The mechanical recycling of ABS through melt processing in injection moulding was a simple method that did not affect the processing characteristics of the material up to three repeated extrusion cycles.

Overall, it appears that recycling of ABS one or twice will generally improve mechanical properties that are lost due to degradation during recycling, with the exception of impact properties. However, the loss of impact strength may be improved by the addition of a suitable impact modifier.

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