Study of Mixing Reprocessed Polycarbonate on Charpy Impact Properties at Increased and Decreased Temperature

Vojtech Senkerik, Michal Stanek, Martin Ovsik

***Abstract*—**The feasibility of reprocessing has been studied as a possible alternative to polycarbonate recycling. The reprocessed polycarbonate was mixed in different proportions with the virgin polycarbonate, and several mixtures were made which were subjected to measurement. The ascertained properties were compared with the virgin material. Polymeric waste from polycarbonate was grinded. The prepared mixtures were subjected to Charpy Impact Properties. This measurement was carried out at two different temperatures, a low temperature minus 23 °C and an elevated temperature of 60 °C. These two temperatures were selected because polycarbonate products are often used in the automotive industry when such temperatures may occur. At low temperature, the results show that the mixtures show less influence on the reprocessed material for the measured properties. At higher temperatures, the effect of reprocessing can be observed, especially the impact of Charpy notch strength.

***Keywords*—**Reprocessed material, preparation of recycled material, temperature, polycarbonate

I. Introduction

THE document The significant development of the production and application of polymer materials began after massive usage of polymers. Over the next few decades, plastics and their processing have significantly developed. Nowadays, polymeric materials are a part of everyday life, and in some cases their use is irreplaceable.

A variety of technologies processes polymers. The core products include injection technology. This technology provides the ability to produce precise and complex (thin-walled) products without the need for further machining. The entire injection cycle is relatively fast and can be fully automated.

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The positives of polymer materials are exported in many negative ways. One of the world's major problems is the question of polymer waste and its processing. Globally, there is a production of large amounts of such waste.

Therefore, there is an increasing tendency to find possibilities for further processing and application of these secondary polymeric raw materials. The number of companies endeavouring to at least partially process these materials is still growing. In most cases, an emphasis is placed on identifying potential recycling before the production of new products. [1-4]

The material used here falls into the group of mid-range engineering plastics. Polycarbonate is used in a very wide range of applications. A great advantage is good mechanical properties at an acceptable cost of manufacturing this material. Despite the increasing processing of secondary materials, there are also growing demands on such made products. Not only the required performance, but also the processing, appearance, methods of further recycling, and more.

The work deals with the possibility of using a secondary raw material in the production of full-fledged injection products. The requirements for the material of the resulting injected product are prescribed. In general, secondary raw materials do not have to meet the specified values separately. Properties can be customized by combining them with the original virgin material. The aim is to find a suitable mixture made using an available recycled material. The observed properties are notch impact properties. On the basis of the physical - mechanical properties test, the resulting mixture could be chosen which could meet the requirements of this polymer material when is used at the elevated temperature of this product. [5-8]

II. Experiment

This article deals with effect of amount of mixing recycled material with virgin polycarbonate to Charpy impact properties. The goal is to perform an experiment in which the products of the studied polymer will be grinded to recycled material and then reprocessed into new specimens. These are then subjected to Charpy impact properties at increased temperatures 60 °C and a low temperature minus 23 °C. This temperature was choose because many products are used at this temperatures.

A. Testing

The mechanical testing was Charpy impact notch test. Testing was performed on the Resil Impact Junior testing machine from company CEAST (Fig. 1). The tests were carried out according to ISO 179. Preparation of individual samples proceeded before each testing. It consisted of making of notch in specimens. Notch was shaped into V-shape with depth of 2 mm.

Fig. 1 CEAST Resil Impactor Junior

Impact tests measure the ability of a material to withstand a high velocity impact, for example, as might be experienced by a plastic kettle dropped from a kitchen worktop. Again, standard methods and specimens are employed; the results give a measure of the toughness of materials. Generally, the methods used fall into two categories. In one, a pendulum strikes a sample and the energy required to break the test piece in one pendulum swing is noted. This is most often seen on data sheets as Charpy or Izod impact tests. Both Charpy and Izod use a standard striking energy.

Samples be notched, the size and shape of the notch is also standardized. This ensures that the samples fracture. The method involves dropping free falling weights onto samples. Free falling drop tests allow higher velocities and impact energies to be achieved. Useful data can also be gathered by doing impact tests at different temperatures as often this reflects more accurately the kind of environmental conditions the plastic will be subject to. For example, how a car bumper performs under impact at 25 ºC may be different to how it performs at -10 ºC. It may become more brittle at low temperatures. Whatever impact test method is employed, polymer degradation should, like tensile testing, show up as a reduction in the property measured. [4]

B. Tested material

Tested material is polycarbonate. This polymer belongs to a group of thermoplastics. It is a linear polycarbonate based on bisphenol A.

Polycarbonate is a very durable material. The outstanding characteristic of PH-HT is its high heat resistance which is combined with great transparency, slight inherent colour, good flow properties and high impact strength, but it has low scratch-resistance and so a hard coating is applied to polycarbonate eyewear lenses and polycarbonate exterior automotive components.

This material is recycled and added to same virgin polycarbonate in different levels of content. [6]

Tab. I Tested mixtures

Recycled material content [%]	Mixture
0	100 % virgin polycarbonate
20	80 % virgin polycarbonate + 20 % recycled material
30	70 % virgin polycarbonate + 30 % recycled material
50	50 % virgin polycarbonate + 50 % recycled material
100	100 % recycled material

C. The specimens

The specimens were prepared by the injection molding technology on the injection molding machine Arburg Allrounder 420C with process parameters Tab. II. Each of the specimens were left to condition for 24 h before testing by the following methods.

Tab. II Process parameters

Melt temperature	300 °C
Mold temperature	100 °C
Ejection temperature	130 °C
Injection speed / pressure	60 mm.s^{-1} / 80 MPa
Holding pressure time / pressure	30 s / 35 MPa
Cycle time	55 s

III. Results

All graphs shows the values in percentages, while virgin polycarbonate represents 100 %. Other values are derived from the nominal values.

A. *Charpy impact notch strength at 60 °C*

The first evaluated parameter is the Charpy impact notch strength used in deflection at the maximum impact force marked as Am. The virgin polycarbonate has an impact strength of 6 kJ/m^2 at 60 ° C.

This value is highest compared to other recycled mixtures. Increasing of the recycled content in the virgin polycarbonate reduces this impact strength. The 20 % mixture shows a drop of nearly 4 % lower than reference material.

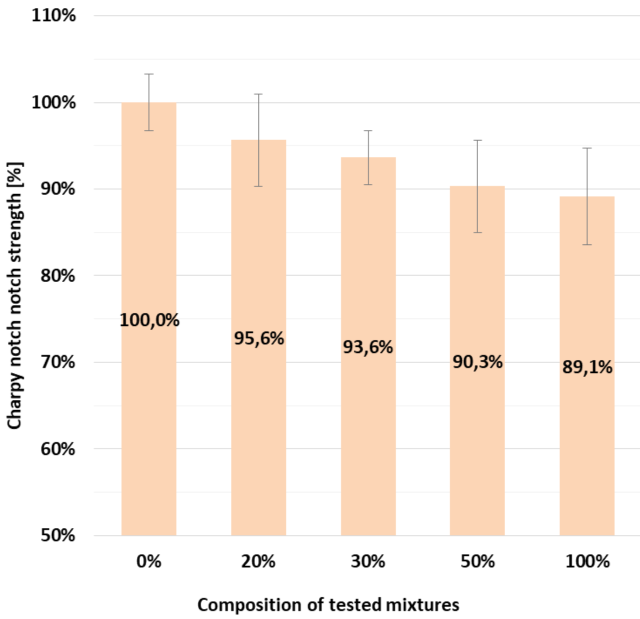

Fig. 2 Charpy impact notch strength at 60 °C

Mixing an additional 10 % recycled material will cause the impact strength to deteriorate by another 2 %. 50 % recycled material adding to the virgin polycarbonate cause the value drop by almost 10 %. On the other hand, the 100 % recycled mixture exhibits a reduction in impact strength of only one percentage point relative to the mixture containing 50 % recycled material.

Tab. III Charpy impact notch strength at 60 °C

Mixture	Arithmetic mean [kJ/m^2]	Standard deviation [kJ/m^2]
0 %	6.00	0.39
20 %	5.74	0.61
30 %	5.62	0.35
50 %	5.42	0.58
100 %	5.35	0.60

There is no such high deterioration in the measured values. 100 % recycled polycarbonate shows a drop of values over ten percent.

Further note that can be seen from the Fig. 2 is that mixtures with recycled additive exhibit greater variations in measured values than the virgin polycarbonate.

B. *Maximum impact force at 60 °C*

Another evaluated property is the maximum impact force exerted by the striking edge on the test specimen in the impact direction marked as *Fm*. The highest measured force is 224.5 N. This value does not show the virgin polycarbonate - but the mixture with the admixture 20 % recycled material. This mixture has only one percent better impact force than the virgin polycarbonate. The mixture with 30 % addition of recycled material shows a reduction in the measured values over two percent.

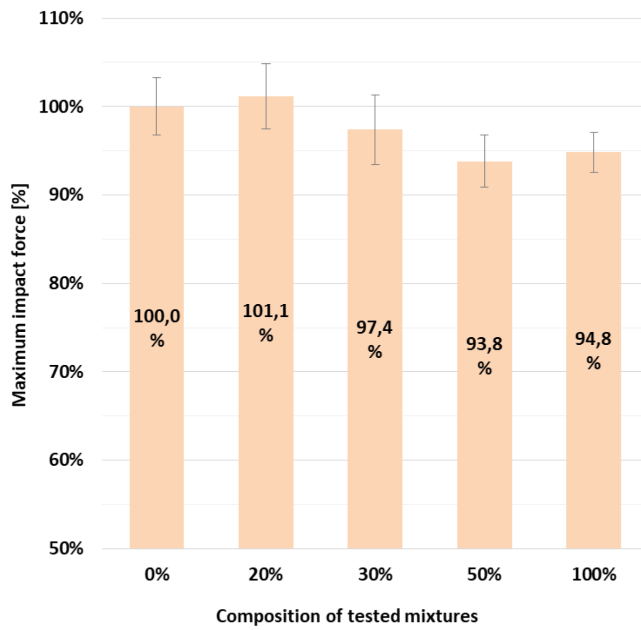

Fig. 3 Maximum impact force at 60 °C

The lowest measured maximum force is for the mixture with 50 % added recycled material, which is less than 6 % than the virgin polycarbonate. Even the mixture from 100 % recycled polycarbonate show better measured maximum force value. This mixture has a higher value of one percent.

All mixtures with admixture of recycled material do not show such a visible decrease in values as for impact notch strength *Am*.

For this measurement, measured values of the maximum force show approximate the same standard deviations for all mixtures with the recycled material including the virgin polycarbonate.

Tab. IV Maximum impact force

Mixture	Arithmetic mean [N]	Standard deviation [N]
0 %	224,5	14,5
20 %	227,0	16,8
30 %	218,6	17,1
50 %	210,6	12,3
100 %	212,9	9,70

C. Deflection at maximum impact force at 60 °C

Deflection at maximum impact force is another evaluated property marked as sm. The lowest deflection value is the virgin polycarbonate and it is 1.95 mm. Other mixtures with the addition of the recycled material exhibit relatively large deflection changes, the largest deflection reaching the mixture with 50 % recycled material. The deflection increased in the Charpy testing more than 8 % for this mixture.

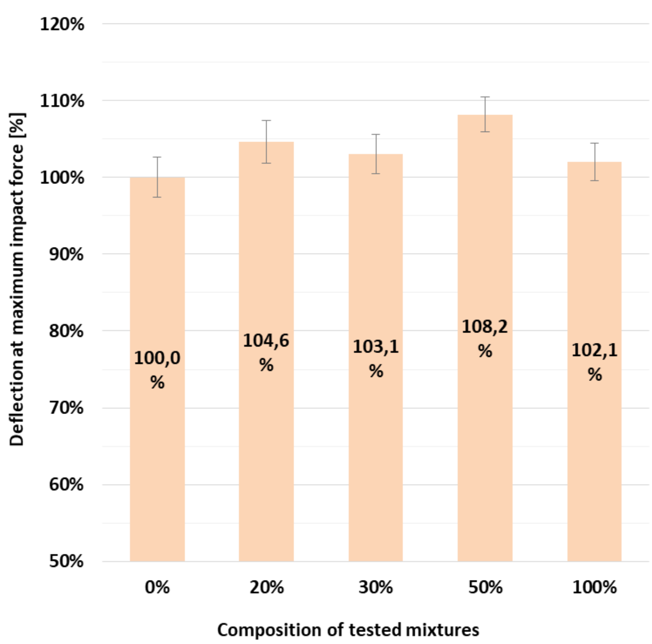

Fig. 4 Deflection at maximum impact force force at 60 °C

The second most deformed samples at Fm show mixture with 20 % recycled material, almost 5 % more deformed than the virgin polycarbonate. The mixture with 30 % recycled material has a deflection of 3 % at maximum force.

On the other hand, the smallest deflection from recycled mixtures shows the 100 % recycled mixture.

Measured data for all mixtures shows almost the same scatter of measured data.

Tab. V Deflection at maximum impact force

Mixture	Arithmetic mean [mm]	Standard deviation [mm]
0 %	1,95	0,1
20 %	2,04	0,11
30 %	2,01	0,1
50 %	2,11	0,09
100 %	1,99	0,09

When comparing the data from the impact strength *Am* with the *sm* deflection, it can be observed that the measured mixtures have less impact strength and even more are deformed.

D. Charpy impact notch strength at - 23 °C

Fig. 5 Charpy impact notch strength measured at temperature minus 23 °C shows minor differences in measured values against to recycled mixtures measured at 60 °C. The virgin material has a maximum impact strength with values of 8.51 kJ/m^2.

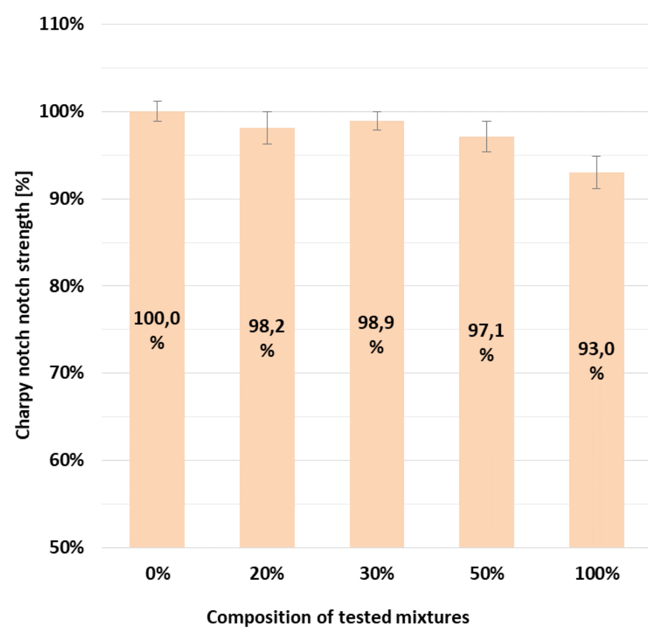

Fig. 5 Charpy impact notch strength at -23 °C

Furthermore, it can be noted that the results show a smaller variance of the measured values, a smaller standard deviation, and thus the resulting mixtures behave constantly.

Tab. VI Charpy impact notch strength at -23 °C

Mixture	Arithmetic mean [kJ/m^2]	Standard deviation [kJ/m^2]
0 %	8.51	0.19
20 %	8.35	0.30
30 %	8.41	0.17
50 %	8.26	0.29
100 %	7.91	0.30

Differences are small for mixtures containing recycled material up to 50 %, decrease in values is up to 3 %. On the other hand, the pure 100% recycled mixture shows a more pronounced drop at this low temperature, this drop being up to 7 % relative to the virgin material.

E. Maximum impact force at -23 °C

Fig. 6 shows the maximum impact force measured at minus 23 °C. The virgin material has a value of a force of 251.5 N. It is a slight increase in this force against measurements at an elevated temperature at 60 °C, this is increased around 27 N.

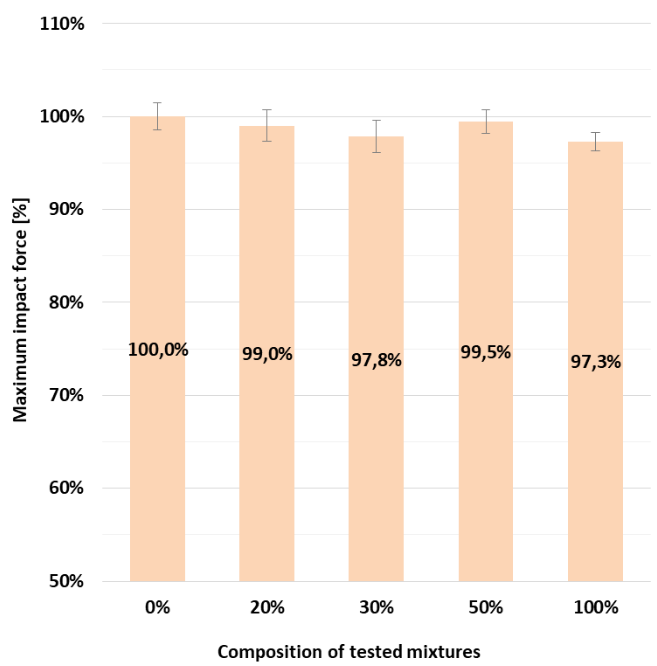

Fig. 6 Maximum impact force at -23 °C

Mixtures with 20 % and 50 % recycled material show almost no changes to the virgin material. A slight decrease of over two percent shows a mixture with 30 % recycled material. The lowest measured value has the mixture that is all recycled; the decline is almost three percent to the virgin material.

Tab. VII Maximum impact force at – 23 °C

Mixture	Arithmetic mean [N]	Standard deviation [N]
0 %	251.5	7.23
20 %	249.0	8.40
30 %	246.0	8.57
50 %	250.1	6.16
100 %	244.7	4.83

F. Deflection at maximum impact force at - 23 °C

The last evaluated parameter is deflection at maximum impact force at minus 23 °C. The virgin material was bent by 2.17 mm. The prepared compositions exhibit relatively uneven deflections in envy with the increasing content of the recycled material. Thus, the trend of deflection cannot be precisely determined by increasing the content of recycled material. However, the differences are visible and can be compared.

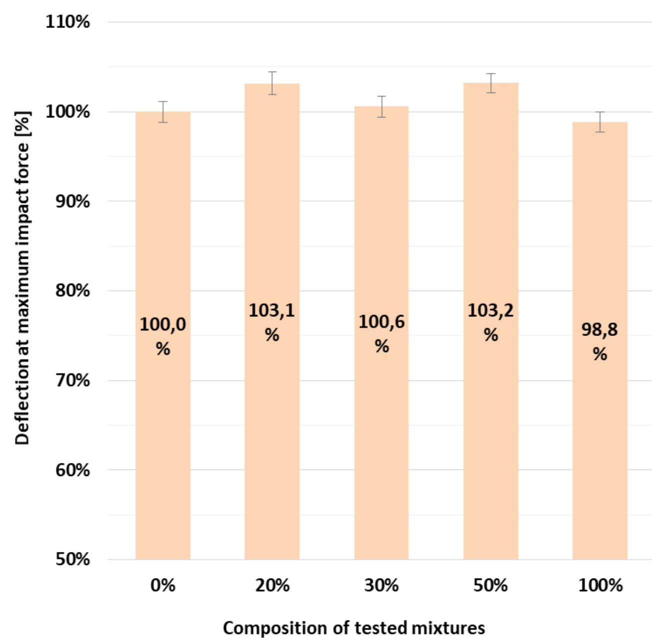

Fig. 7 Deflection at maximum impact force force at -23 °C

But it can determine behavioral changes. The 30 % recycled mixture shows similar values to the virgin material. Mixtures with 20 % and 50 % recycled material deformed by more than three percent. On the other hand, the mixture of 100 % recycled material has a lower deflection; this value can be determined by the fact that this mixture exhibits relatively worse properties for both impact force and Charpy impact notch strength.

Tab. VIII Deflection at maximum impact force

Mixture	Arithmetic mean [mm]	Standard deviation [mm]
0 %	2,17	0.039
20 %	2,24	0.045
30 %	2,18	0.039
50 %	2,24	0.036
100 %	2,15	0.036

IV. Conclusion

This study dealt with the reprocessed of polymeric waste from polycarbonate. The prepared grinded material was mixed at various concentrations with the virgin material PC-HT. The impact of reprocessing has been investigated using Charpy Impact Properties. The measurements were made at a low temperature minus 23 °C and an elevated temperature of 60 °C, because polycarbonate products are often used at these temperatures. Injection molding technology was used for the original products, that were waste and for the production of test specimens for measurement.

The effect of the reprocessed material is most visible in Charpy impact notch strength. At elevated temperatures, the gradual decrease in the values of all the mixtures. The largest decrease is reported by pure 100 % recycled material, which has a worse strength up to ten percent. At low temperatures, differences are not significant for all mixtures except 100 % recycled mixture, with a decrease of nearly seven percent.

The results of the maximum impact force show a lesser impact of reprocessing. At both temperatures, this measured value decreases to approximately five percent.

The last observed property was deflection at maximum impact force. There was an increase of this deformation by an average of three percent at both temperatures. Only 50 % recycled mixture has a deformation up to eight percent higher than the virgin material.

Mixtures with a smaller concentration of reprocessed material up to 30 % show small changes in observed properties. This work only dealt with the first reprocessed of the material. More significant changes would be reflected in multiple reprocessing of this polycarbonate.

Acknowledgment

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