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THE EFFECT OF THERMAL DAMAGE ON THE MECHANICAL PROPERTIES OF POLYMER REGRINDS

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SUMMARY

Reprocessed polymers are subjected to high processing temperatures that result in the breakdown of molecular chains and changes in the molecular structures. These phenomena reflect in the mechanical properties of materials. Practically every regrind is seen as a new material.

These experiments deal with the molding, regrinding, and reprocessing of test specimens for the study of their mechanical properties. The comparative test data from each recycled material would give students an insight of the molecular structures and property degradation.

Three important rheological and mechanical properties such as melt flow, impact strength, and flexural strength are to be determined. These properties play key roles in the selection of engineering materials.

The material selected for demonstration was Makrolon 3000L, a polycarbonate thermoplastic from Bayer AG. The thermal degradation due to repeated processing reflects in the decrease in molecular weight and breakdown of molecular chains causing increase in melt flow. The Izod-impact resistance and the flexural strength deteriorate gradually.

INTRODUCTION

The demand for plastics has increased tremendously over the last decade. More than half of the demand for polycarbonate goes into communications and electronics. As demand increases in the more critical engineering applications, the use of all available feed stock, even regrind, becomes a necessary requirement.

This work investigates the effect of reprocessing on the mechanical properties of polycarbonate. The polycarbonate material studied was Makrolon 3000L manufactured by Bayer AG.

Polymers are exposed to heat and mechanical shearing during injection molding, which results in the breakdown of molecular chains. Practically every regrind is seen as a new material. The author suggests that the students should mold their own specimens and regrind and reprocess the same material using appropriate processing parameters. The comparative test data from each recycled material give students an insight of the molecular structures and corresponding property degradation. Three important mechanical and rheological properties, such as melt flow, impact strength, and flexural strength can be easily determined and play key roles in the selection of engineering materials.

TESTING OF MECHANICAL PROPERTIES

Equipment

Injection molding machine, scrap grinder, flexural stress tester, impact tester, and melt flow measuring instrument.

Test Specimens

Test specimens were prepared according to DIN 53452 for flexural stress and according to DIN 53453 for izod impact tests.

50mm x 6mm x 4mm test specimens were injection molded. The specimens were molded at 310 C with a cycle time of 40 seconds. Specimens for impact tests had a notch 0.9 mm wide and 1.3 mm deep.

To start 300 specimens were molded, tested, and reground. Then 240 specimens were molded with the same processing parameters, tested, and reground. The third, fourth, and the fifth molding followed.

Test procedure

For every processing ten specimens were tested for flexural stress, twenty specimens for impact strength, and five readings were taken for melt flow readings.

Flexural stress

The specimens were placed on supports at both ends and load applied at the center until failure. Figure 2 shows the testing apparatus manufactured by Zwick. Bending stress was calculated using the applied load, the bending moment, and the moment of inertia of the sample.

$$\text{Flexural stress } \sigma_b = M/(I/c) \quad \text{(MPa)}$$
$$I/c = bh^2/6$$

b=width of the specimen
h=height of the specimen

M=bending moment= PL/4
P=load at the center

Notched Izod impact test

Izod impact tests were done on an impact tester from Zwick. The energy required to break a notched sample with respect to the area under the notch is considered as impact strength. The test is done by clamping a specimen in the base of a pendulum testing machine. The pendulum is released and the energy consumed in breaking the sample was recorded. The impact strength was calculated by using the energy as recorded by the tester and the cross sectional area of the sample.

$$\text{Impact strength } \alpha = E/(bh_k) \quad (kJ/m^2)$$

E=energy reqd. to break the sample
b=width of the sample
h=height of the sample

Melt flow

The melt flow test indicates relative flowability of polymers in the melt form. It is the most basic test on thermoplastic polymers.

Melt flow of a polymer is determined by the amount of viscous polymer forced through a standard orifice at a certain temperature under load for a certain time. The melt flow apparatus is shown in figure 3.

RESULTS AND DISCUSSION

A set of sample test results for only the first moldings are given at the end of this paper. Table 1 shows the results on flexural tests, table 2 shows the results of notched izod impact tests, and the results of melt flow test are given in table 3. Finally a summary of the test results for all five moldings is given in table 4 which is also graphically reproduced in figure 4.

Flexural Stress

Bending stress, a form of fatigue, is a unique stress with characteristic mechanisms that are distinctly different from those of static or impact stresses. Bending stress data are helpful in understanding plastic fatigue performance, ranking materials, and qualitatively guiding design.

The data on bending stresses shows a wide variety of results. The Makrolon 3000L molded at 310 C remained relatively the same until the third molding in which a slight increase in resistance was observed, after which a significant decrease occurred. This may be explained by a difference in fiber orientations, or a difference in melt flow or significant decrease in the molecular weight.

Notched Izod impact test

During impact testing , the specimens undergo three stages of development. The elastic stage, then the crack propagation stage and finally the separation stage. As the specimens are remolded, a significant decrease in impact resistance is observed. As the material is recycled, its thermal history is changed as well as the flow patterns.

Melt Flow

The melt flow increases with each cycle because of main chain scission. The Makrolon 3000L experienced a significant increase in melt flow between the first and the fourth moldings but basically leveled off at the fifth. This is the result of the high processing temperature which causes a decrease in molecular weight and a breaking down of the materials' main chains.

TABLE 1
Flexural Test
Makrolon 3000L
First Molding

Specimen	Load (N)
1	151.76
2	154.02
3	152.06
4	152.06
5	156.96
6	153.04
7	151.56
8	157.94
9	155.98
10	151.56

TABLE 2
Notched Izod Impact Test
Makrolon 3000L
First Molding

Specimen	Energy (J)
1	0.761
2	0.790
3	0.682
4	0.775
5	0.741
6	0.834
7	0.780
8	0.736
9	0.510
10	0.804
11	0.844
12	0.530
13	0.804
14	0.824
15	0.569
16	0.608
17	0.765
18	0.716
19	0.608
20	0.824

TABLE 3
Melt Flow Test
Makrolon 3000L
First Molding

Time (min)	Weight (g)
0	-
2	0.5925
4	0.6330
6	0.6607
8	0.6615
10	0.6305

Melt Index = 3.185/10min

TABLE 4
SUMMARY OF TEST RESULTS

Temperature 310° C	Molding	Impact Strength kJ/m²	Bending Stress MPa	Melt Flow g/10min
Makrolon 3000L	1	44.83	96.82	3.18
	2	32.08	95.94	3.64
	3	15.79	98.30	6.65
	4	4.02	broken	12.33
	5	4.02	broken	12.33

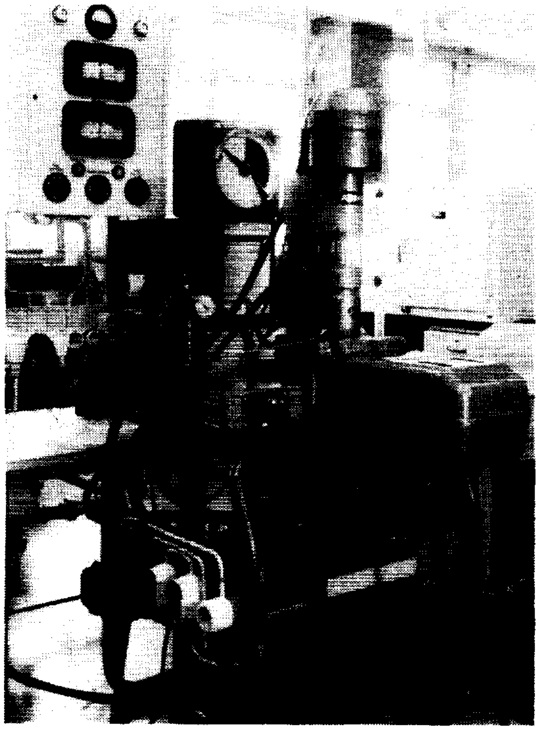


Figure 1. Injection molding machine

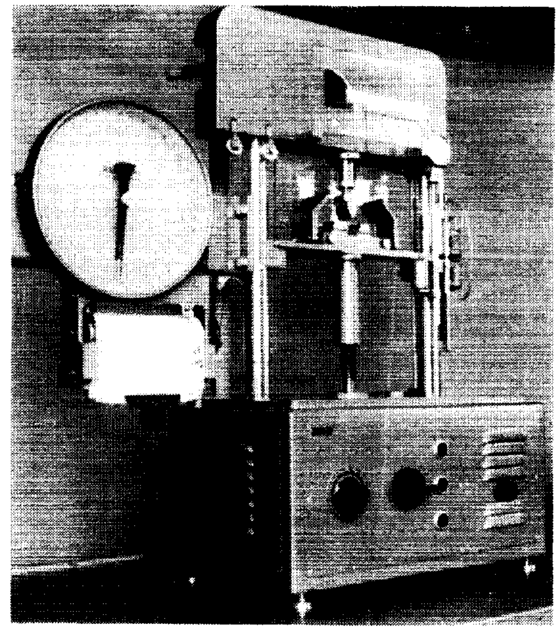


Figure 2. Flexural stress tester

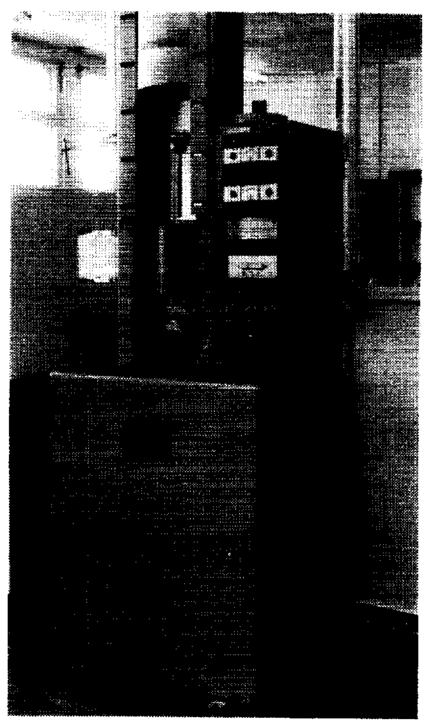
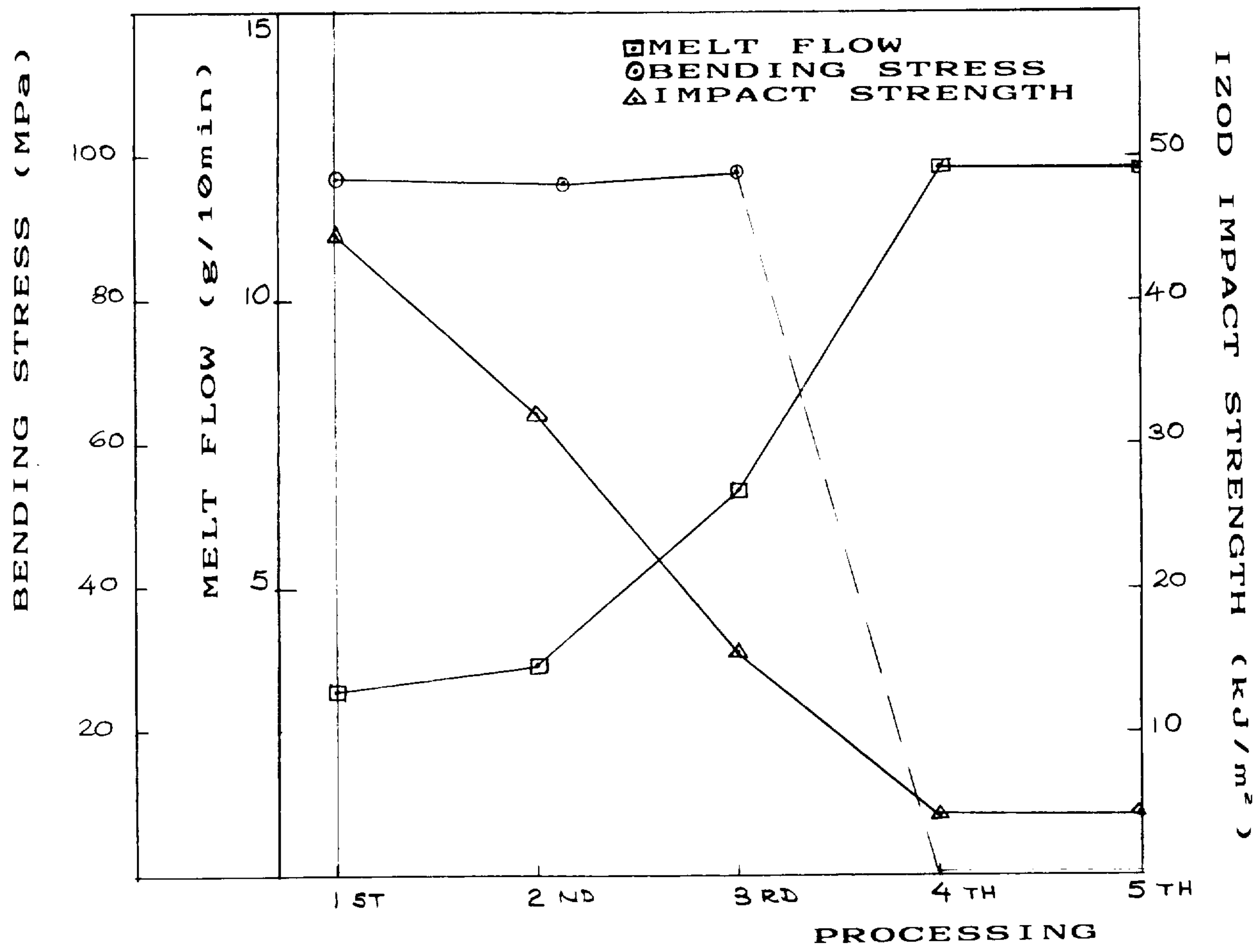


Figure 3. Melt flow apparatus



BENDING STRESS (MPa)
100
80
60
40
20
MELT FLOW (g/10min)
15
10
5
MELT FLOW
BENDING STRESS
IMPACT STRENGTH
IZOD IMPACT STRENGTH (kJ/m²)
50
40
30
20
10
1 ST
2 ND
3 RD
4 TH
5 TH
PROCESSING

FIGURE 4