

CHAPTER III

RESULTS AND DISCUSSION

3.1 Nylon 6,6

Babatapet and Isaac (1992) reported the tensile strength of Zytel 101 is in the range of 65-75 Mpa which agree with the experimental data. Tensile strength, flexural strength and impact strength, which are shown in figure 3.1, 3.2 and 3.3, respectively, have the value in the range of the specification as shown in Table 3.1.

Table 3.1 The mechanical properties of nylon 6,6 (Zytel 101)

Tensile strength (5.1 mm/min, Mpa)	77.2-82.7
Flexural strength (1.3 mm/min, MPa)	-
Izod impact strength (J/m)	53-112

The flexural strength and tensile strength increased after the first pass of reprocessing and started to drop after the fifth reprocessing pass. The impact strength decreased after number of passes increased. Y.P. Khanna studied the processing history vs. crystallization rate of nylon 6 showed that the tensile strength of the extruded resin increased from the virgin material due to a difference in crystalline morphology. The extruded resin has a smaller spherulites than the virgin material. They also found that the percentage of crystallinity increased after reprocessing. The amount of crystalline structure influences the mechanical properties

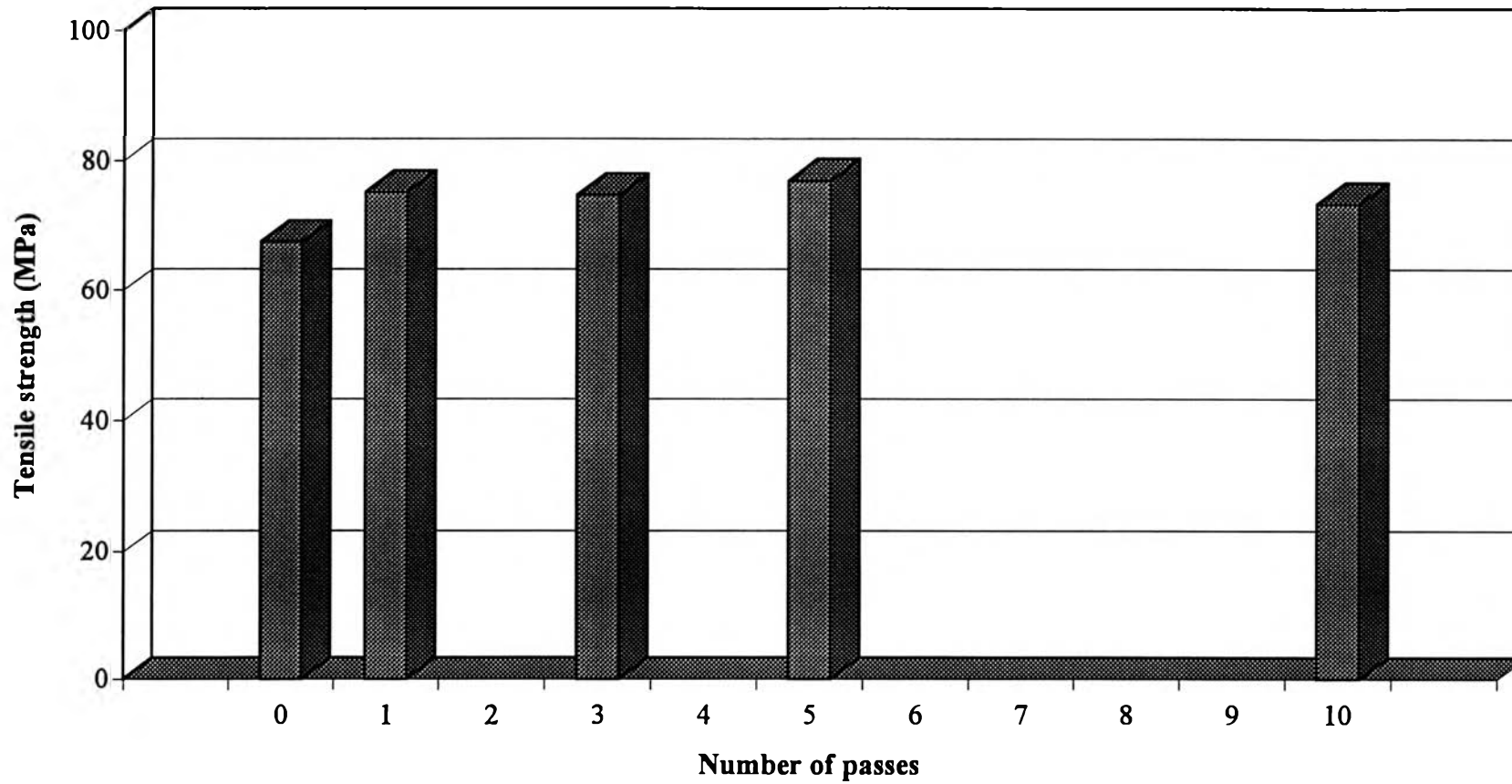


Figure 3.1 The tensile strength of reprocessed nylon 6,6.

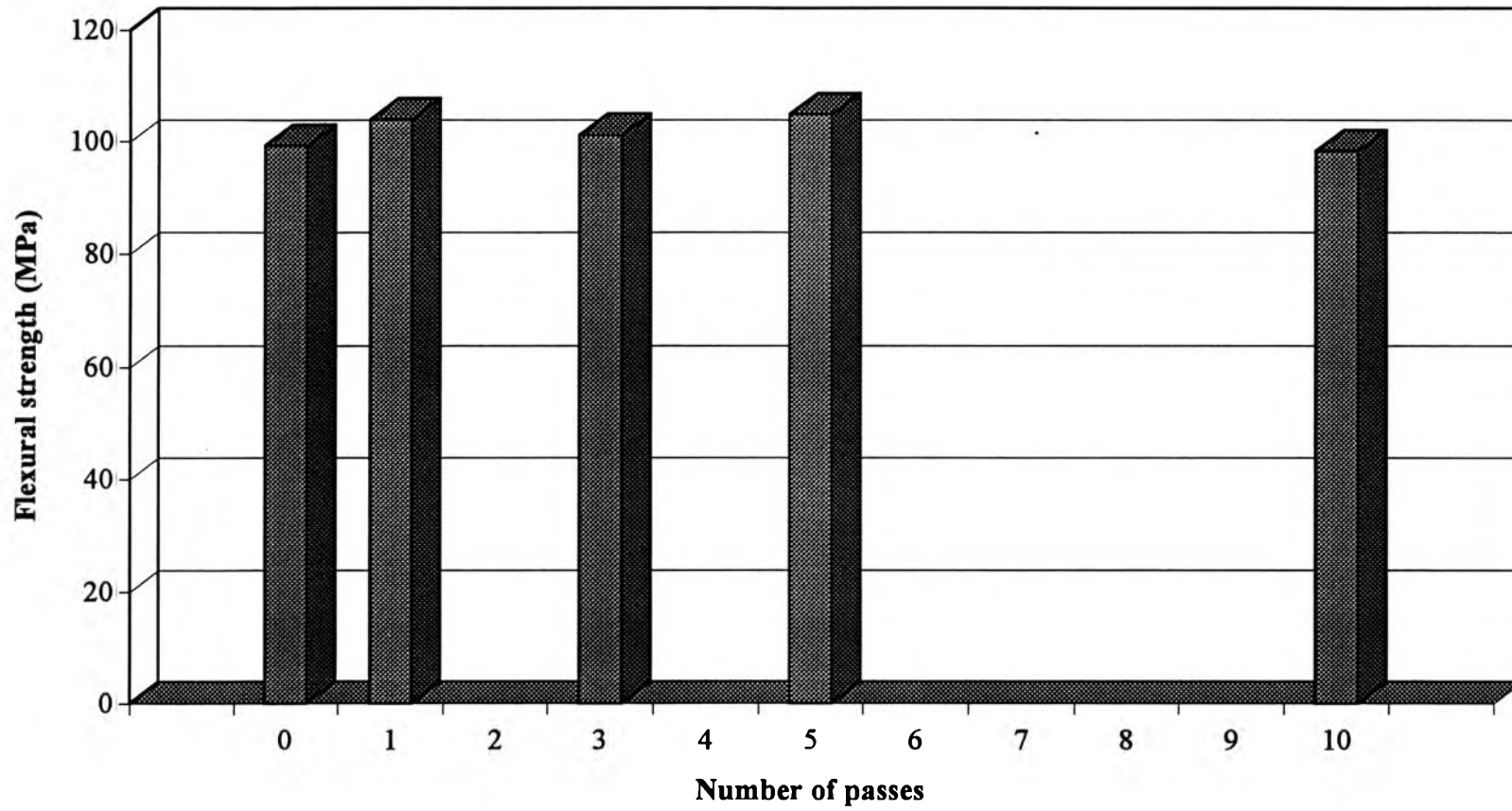


Figure 3.2 The flexural strength of reprocessed nylon 6,6.

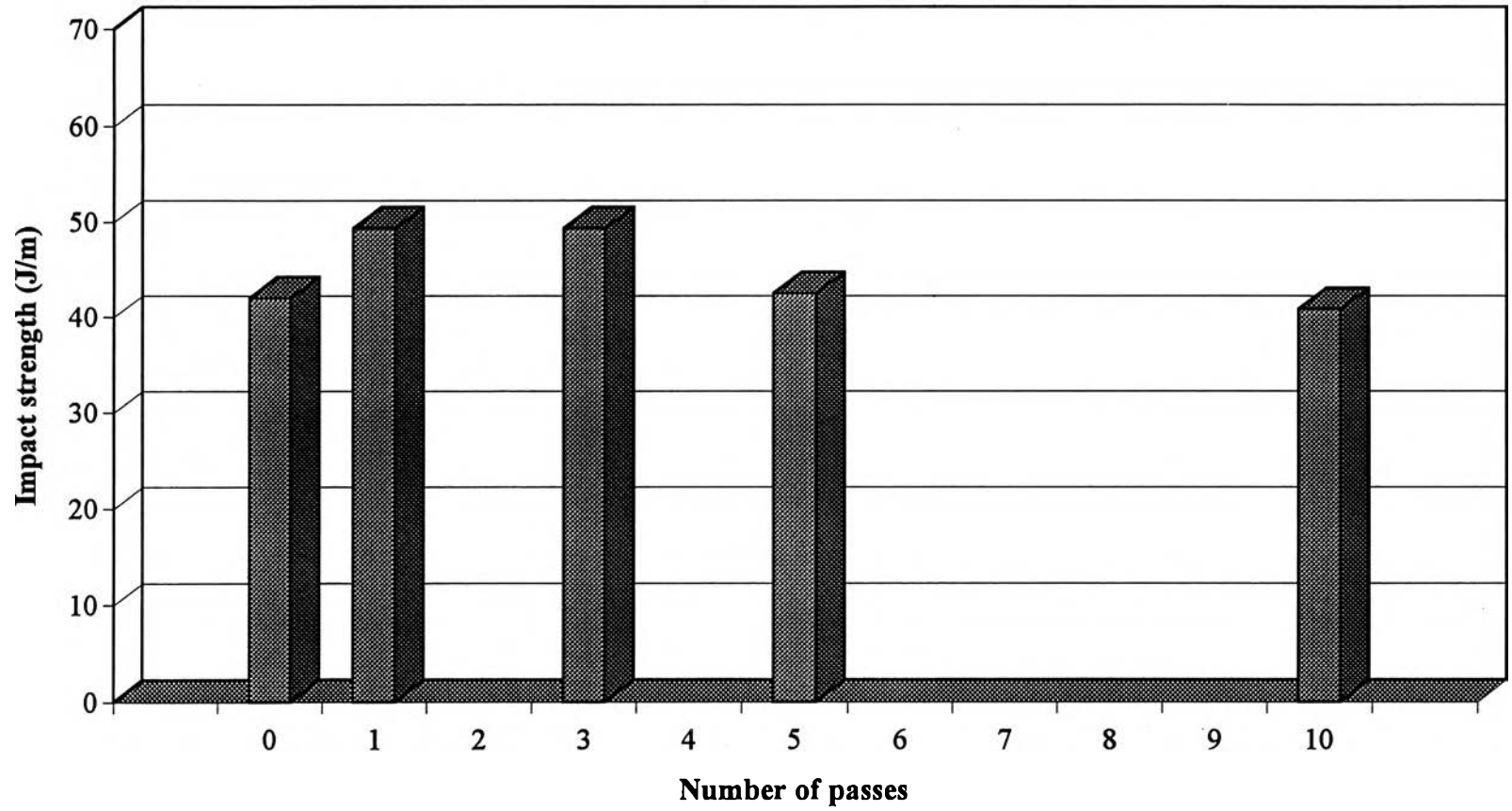


Figure 3.3 The impact strength of reprocessed nylon6,6.

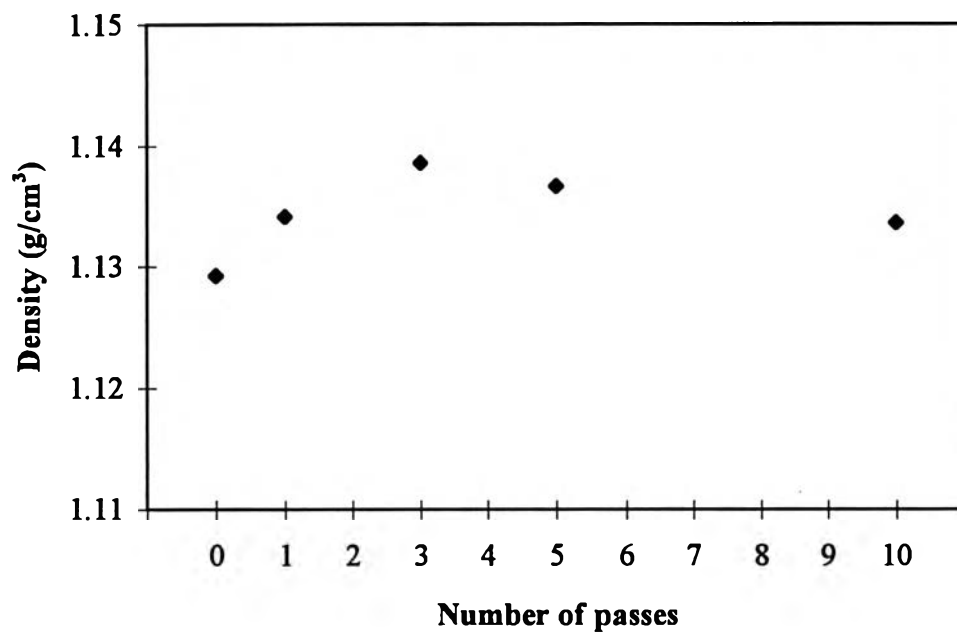


Figure 3.4 The density of reprocessed nylon 6,6.

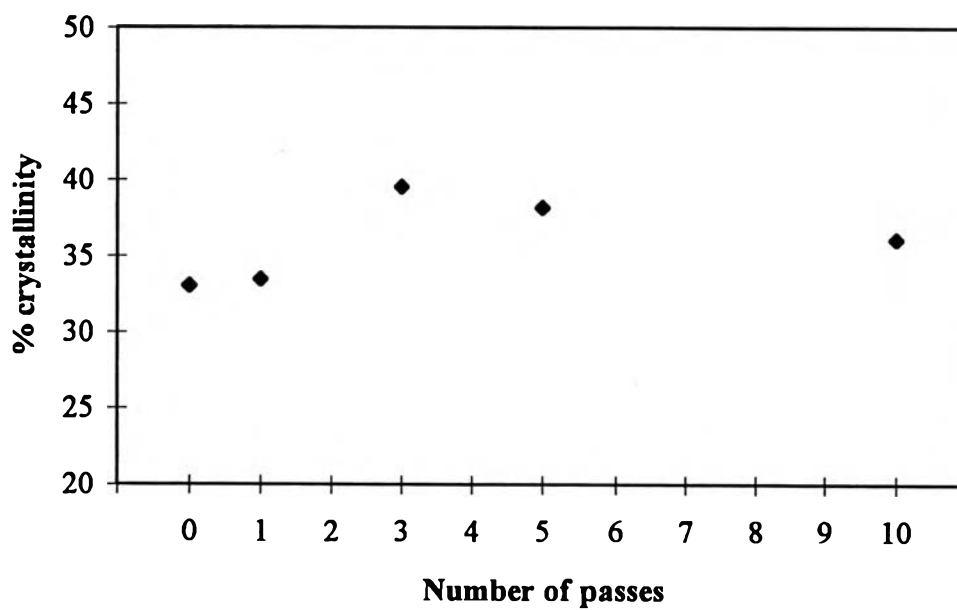


Figure 3.5 The percentage of crystallinity of reprocessed nylon 6,6.

1993 ; MARGOLIS, 1985]. High degree of crystallinity promoted the stiffness of the material than toughness which means higher the percentage of crystallinity, higher the tensile strength and flexural strength, but lowers the impact strength.

To confirm the above argument density measurement has been carried out. The crystals structure are denser than amorphous structure due to the more efficient chain packing. The result from this experiment indicated that density actually increased as shown in figure 3.4. The percentage of crystallinity (X_c) can be calculated from the density data by this equation [BRANDUP, 1991];

$$X_c = 830 - \frac{900}{\text{density}}$$

The percentage of crystallinity with number of passes was plotted in figure 3.5. The percentage of crystallinity increased from 33% to 37-40% after reprocessing. This result agrees with the mechanical strength data that after reprocessing the percentage of crystallinity has increased.

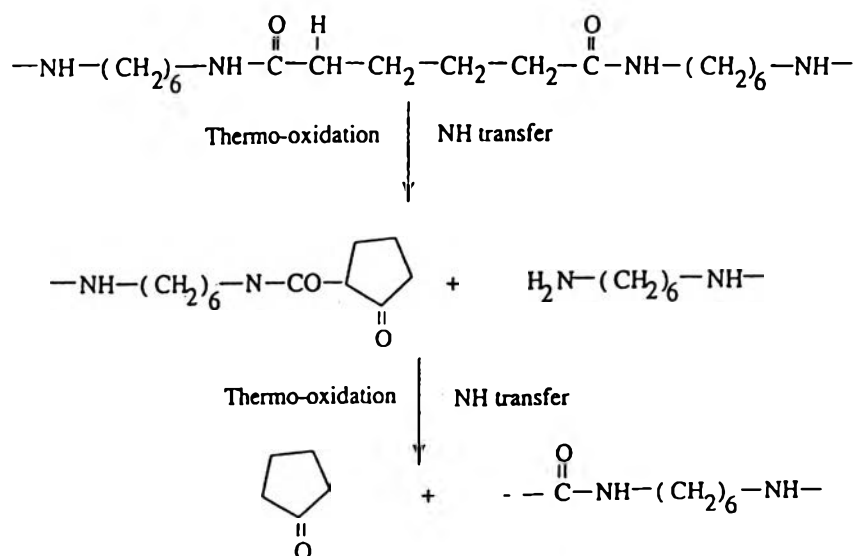


Figure 3.6 The thermo-oxidation of Nylon 6,6.

Nylon 6,6 is a semicrystalline polymer [MARK, 1986; MARGOLIS, 1985]. The mechanical properties of nylon 6,6 are largely controlled by the percentage of crystallinity and it is susceptible to thermo-oxidation in air at elevated temperature which is shown in figure 3.6.

Hydroperoxide is produced and then decomposes to a variety of products by chain scission (carbon dioxide, ammonia, and some cyclopentane) [MARGOLIS, 1985].

Thermo-oxidation results in a lower molecular weight and loss in mechanical properties [SCHNABEL, 1990]. J.E. Nightingale noted that the molecular weight of 25 % re-use composition of nylon is substantially constant after 4 passes of reprocessing. The amount of degradation is negligible and it is difficult to detect any falling-off in mechanical properties. Shah et.al. reported that nylon 6,6 (Zytel 101) shows a significant thermal degradation at 288 °C and the processing condition which was used in this study was 285 °C. This previous work supports the result which shows in figure 3.1, 3.2, and 3.3 that tensile and flexural strength did not change after the first pass of reprocessing because there was no significant thermo-oxidation during the processing. However, after the fifth pass of reprocessing the degradation of nylon 6,6 reduced the mechanical properties.

Our results indicate that the mechanical properties are not significantly changed by reprocessing before the fifth pass of reprocessing because the small amount of degradation does not affect the molecular weight and the mechanical properties of nylon 6,6. However, impact strength tended to be adversely affected due to higher the percentage of crystallinity.

3.2 Polyoxymethylene (POM)

Du Pont (1996) reported that acetal homopolymer, general purpose grade, has tensile strength 69 MPa and Izod impact strength 75 J/m which agree with the experimental data which are shown in figure 3.7 and 3.9 , respectively. And the experimental data agree with the specification of the material which is shown in table 3.2.

Table 3.2 The mechanical properties of Polyoxymethylene (Delrin 500)

Tensile strength (5.1mm/min, MPa)	69
Flexural strength (1.3 mm/min, MPa)	97
Izod impact strength (J/m)	80

From figure 3.7, 3.8, and 3.9 tensile and flexural strength of POM constant after reprocessing while impact strength increased as number of passes increased. The density plotted in the figure 3.10 shows a constant density after reprocessing. The size of the crystalline structure formed will also be a significant factor [J.A.BRYDSON,1982]. The spherulite size is increased and that decreases the impact toughness[J.A.BRYDSON,1982 ; MARGOLIS,1985]. Y.P. Khanna et.al. studied the morphology of nylon 6 after reprocessing and quote the difference of the crystalline after reprocessing , the extruded resin has smaller spherulite than virgin material which agree with the result that the impact strength increased because of the smaller spherulite of the material after reprocessing.

The molecular weight can be calculated from MFI data, which is shown in figure 3.11, following the equation [BRANDUP, 1991] ;

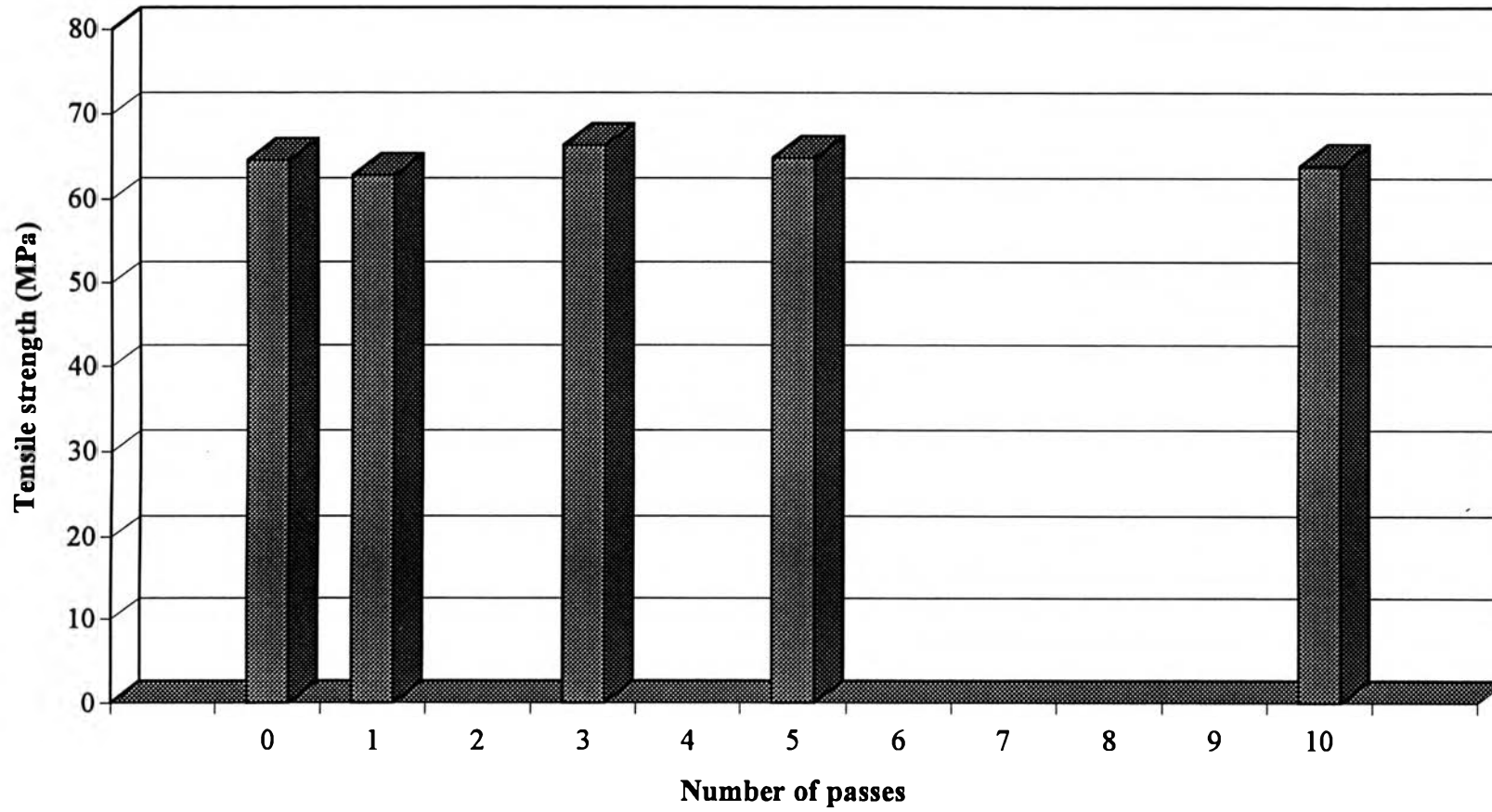


Figure 3.7 The tensile strength of reprocessed polyoxymethylene.

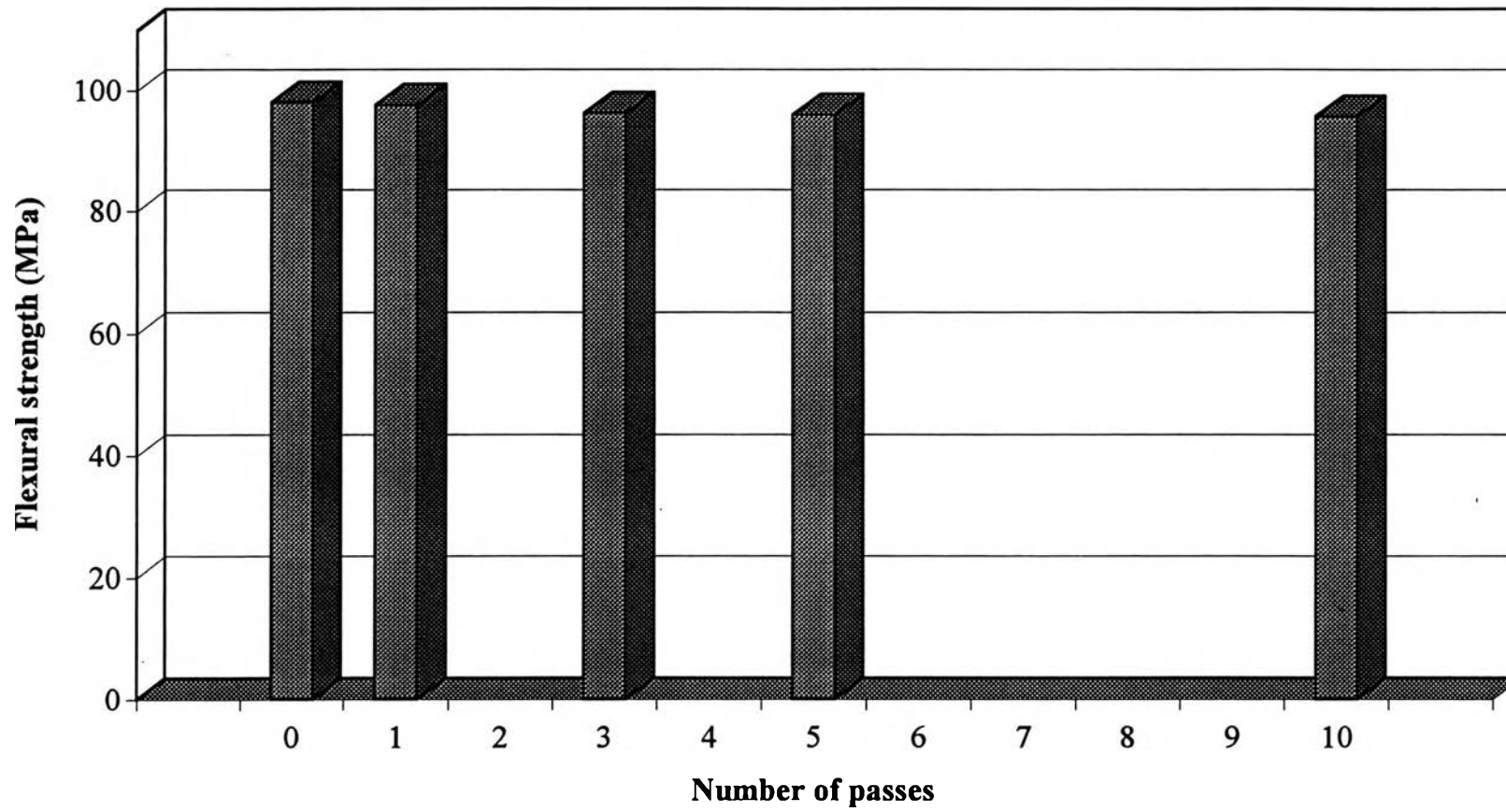


Figure 3.8 The flexural strength of reprocessed polyoxymethylene.

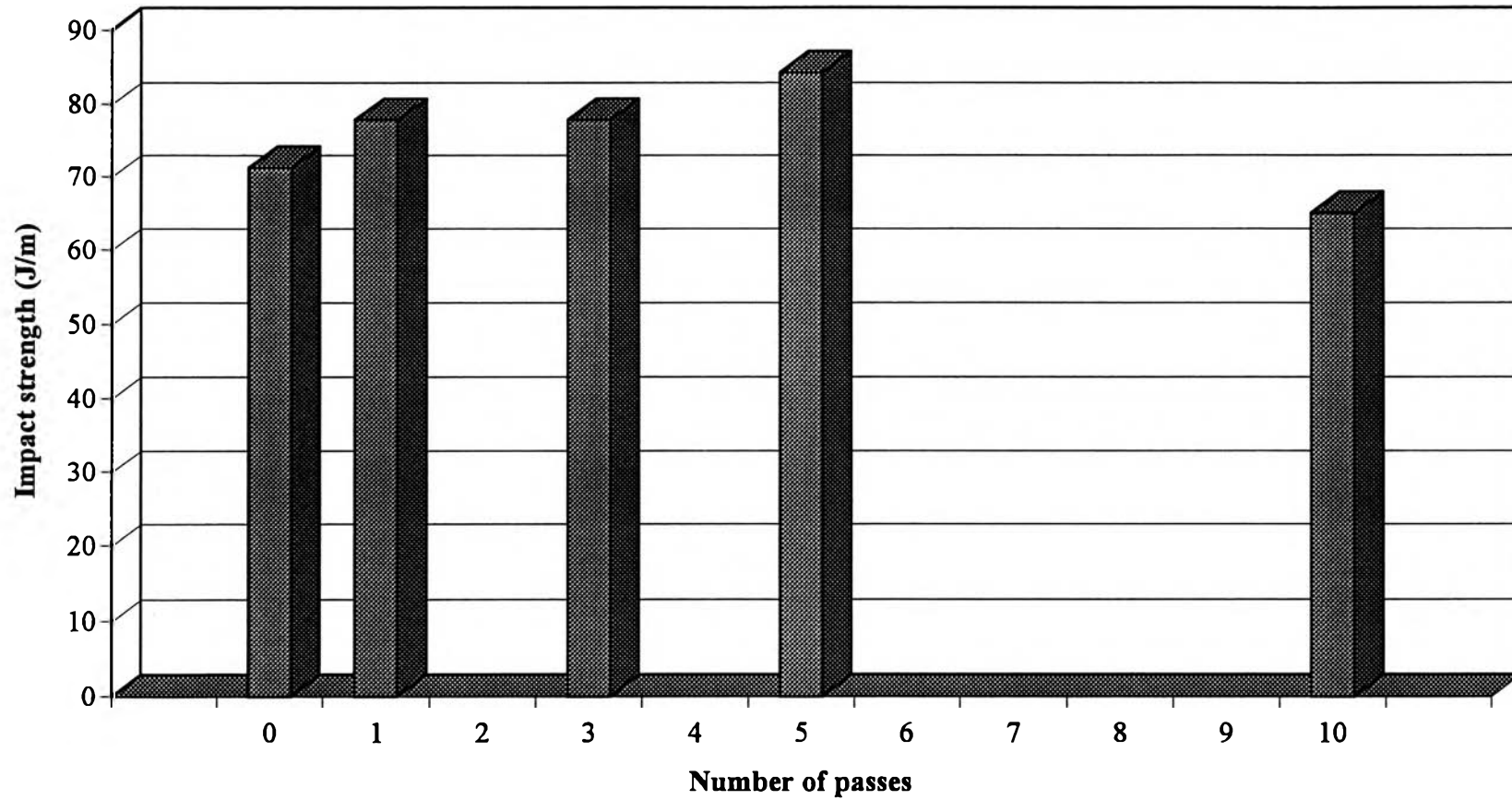


Figure 3.9 The impact strength of reprocessed polyoxymethylene.

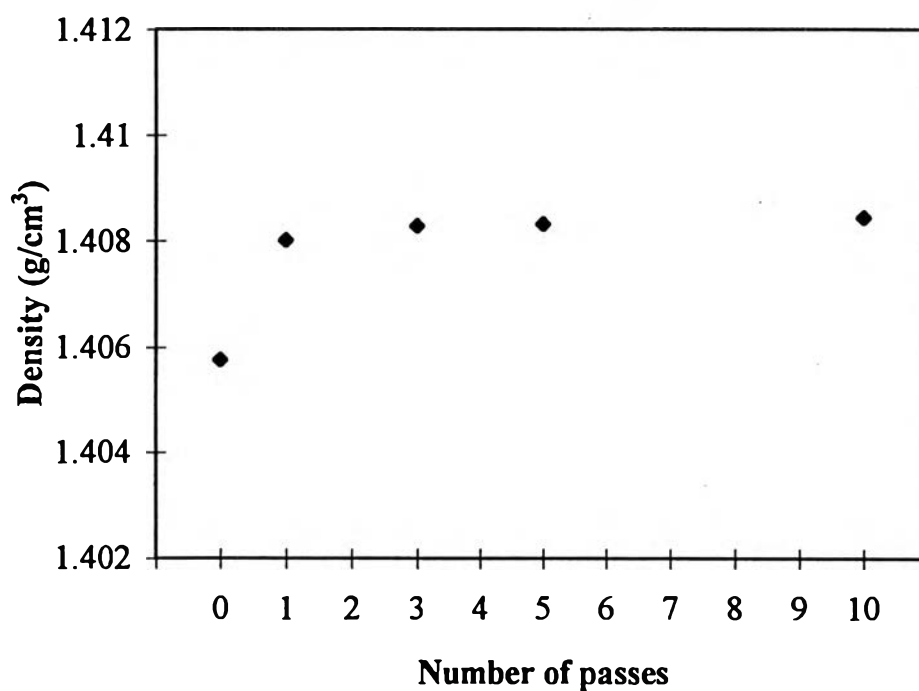


Figure 3.10 The density of reprocessed polyoxymethylene.

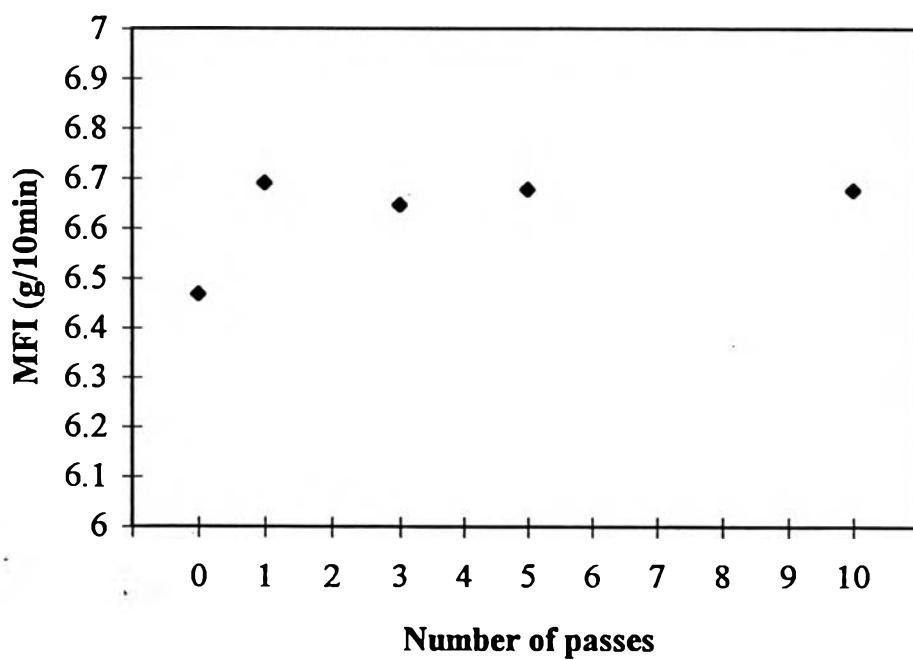


Figure 3.11 The Melt Flow Index of reprocessed polyoxymethylene.

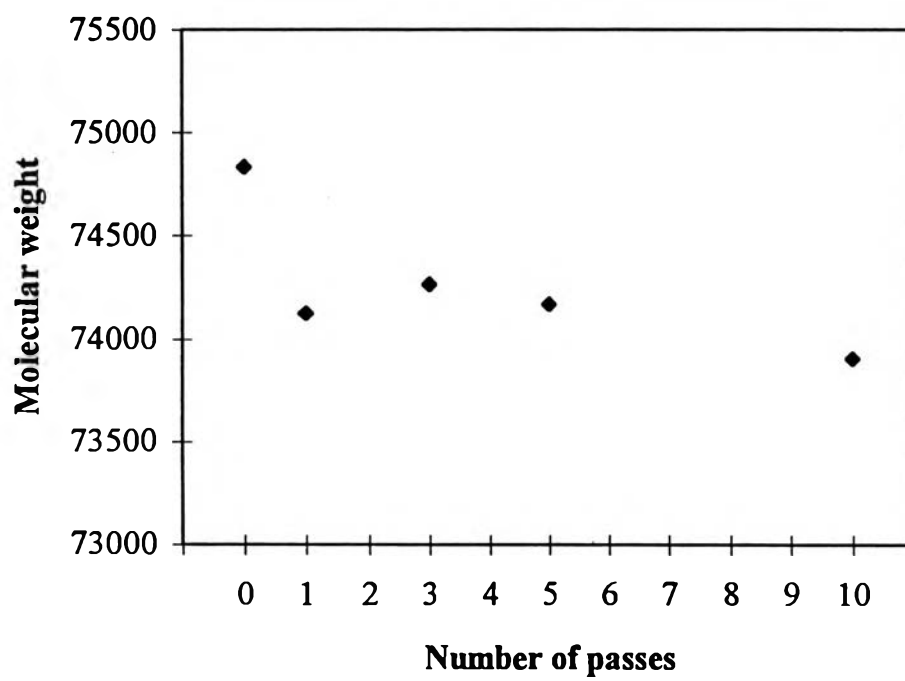


Figure 3.12 The molecular weight of reprocessing polyoxymethylene .

$$\text{MFI} = 1.38 \times 10^{-18} (\text{MW})^{-3.5}$$

Using this expression, the molecular weight was plotted as a function of the number of passes. Figure 3.12 shows the decrease of molecular weight after reprocessing. There are 4 paths which lead to degradation of POM [GRUENWALD, 1993]

1. thermal unzipping of end group to formaldehyde monomer
2. thermo-oxidation attack on the backbone, causing chain scission to an unstable end group and subsequent depolymerization through “unzip”
3. acidic attack on backbone causing chain scission and unzipped
4. thermal chain scission of the CH₂-O- bond at temperature above 270 °C leading to “unzipping”

But Delrin has hydroxyl end group that are acetylated end group to prevent the depolymerization by an unzipped reaction that occur at 127 °C [BRANDUP, 1991] hence the small amount of degradation occurs which leads to 1-2 % of increasing of MFI and decreasing of molecular weight which are shown in figure 3.11 and 3.12, respectively. As seen in the previous work that polyacetal shows some decrease in melt viscosity because of thermal instability at high temperature. The degradation of POM lead to the increase of chain end. The hindering effect of the end group may result in greater disturbances when crystallization [A.A COLLYER, 1990]. The increase of end group leads to the decreased of spherulite size which increases the impact strength.

The result indicated that the reprocessing gave loss of molecular weight and decreased melt viscosity. However, there are only 1-2 % change of molecular weight. Because the regularity of chain promotes the chain close packing, the density of POM was not significantly change. and the mechanical properties were not affected by the reprocessing except the impact strength which trended to increase after reprocessing.

3.3 Polyetherimide (PEI)

The experimental data of PEI are shown in table 3.3 and agree with the report of Floryan and Serfaty (1982).

The mechanical strengths of PEI are shown in figure 3.13, 3.14, and 3.15. The flexura strength, the tensile strength and the impact strength slightly dropped after reprocessing.

Table 3.3 The mechanical strength of Polyetherimide (Ultem1000)

Tensile strength (5.1 mm/min, MPa)	105
Flexural strength (1.3 mm/min, MPa)	150
Izod impact strength (J/m)	50

PEI is a completely amorphous polymer. Amorphous polymers are usually considered to be randomly entangled molecules [JEAN-MICHEL, 1991]. It is , however, apparent that completely random packing cannot occur. PEI can act as pseudo-crosslink or physical crosslink and upon drawing it can

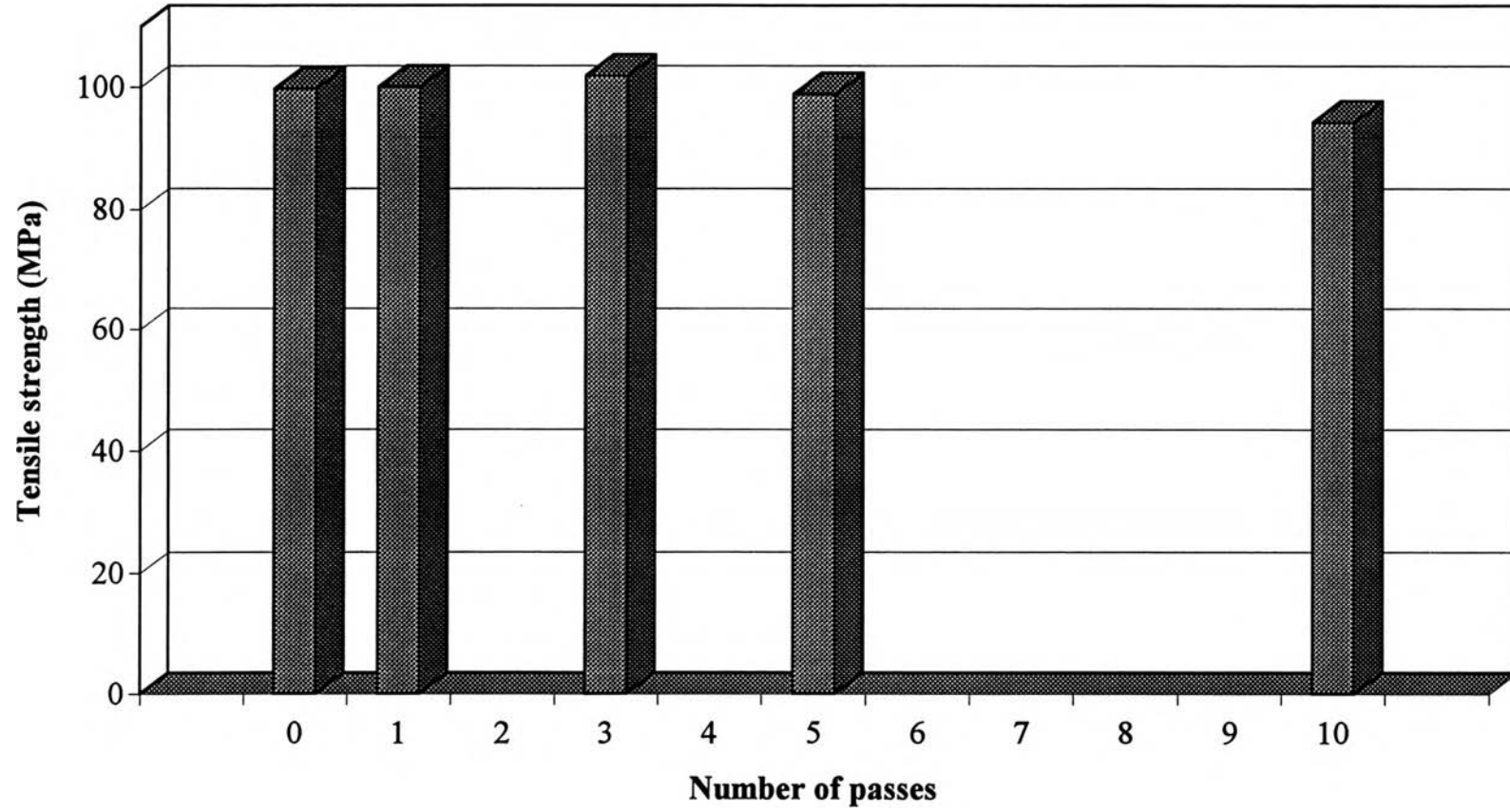


Figure 3.13 The tensile strength of reprocessed polyetherimide.

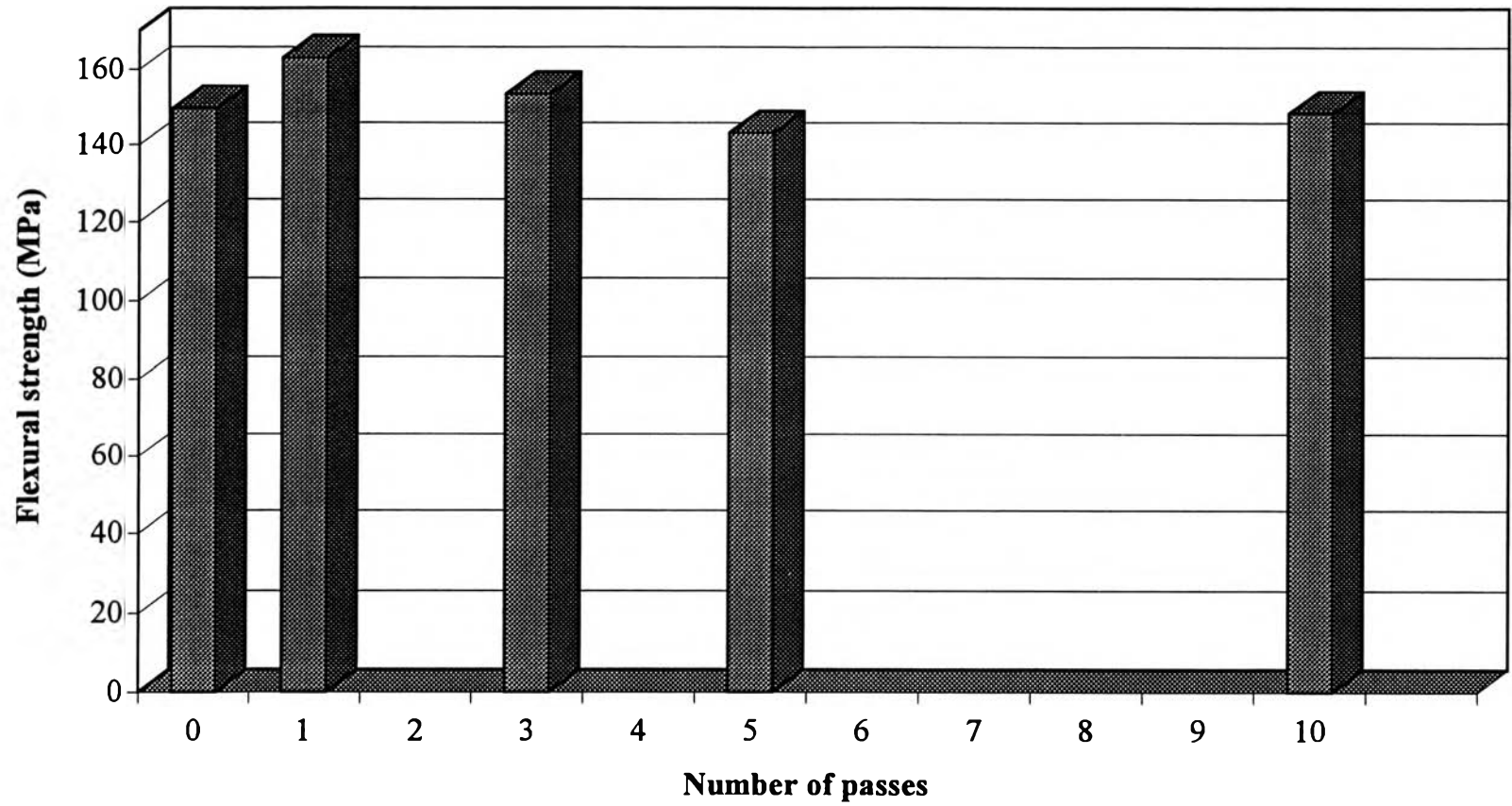


Figure 3.14 The flexural strength of reprocessed polyetherimide .

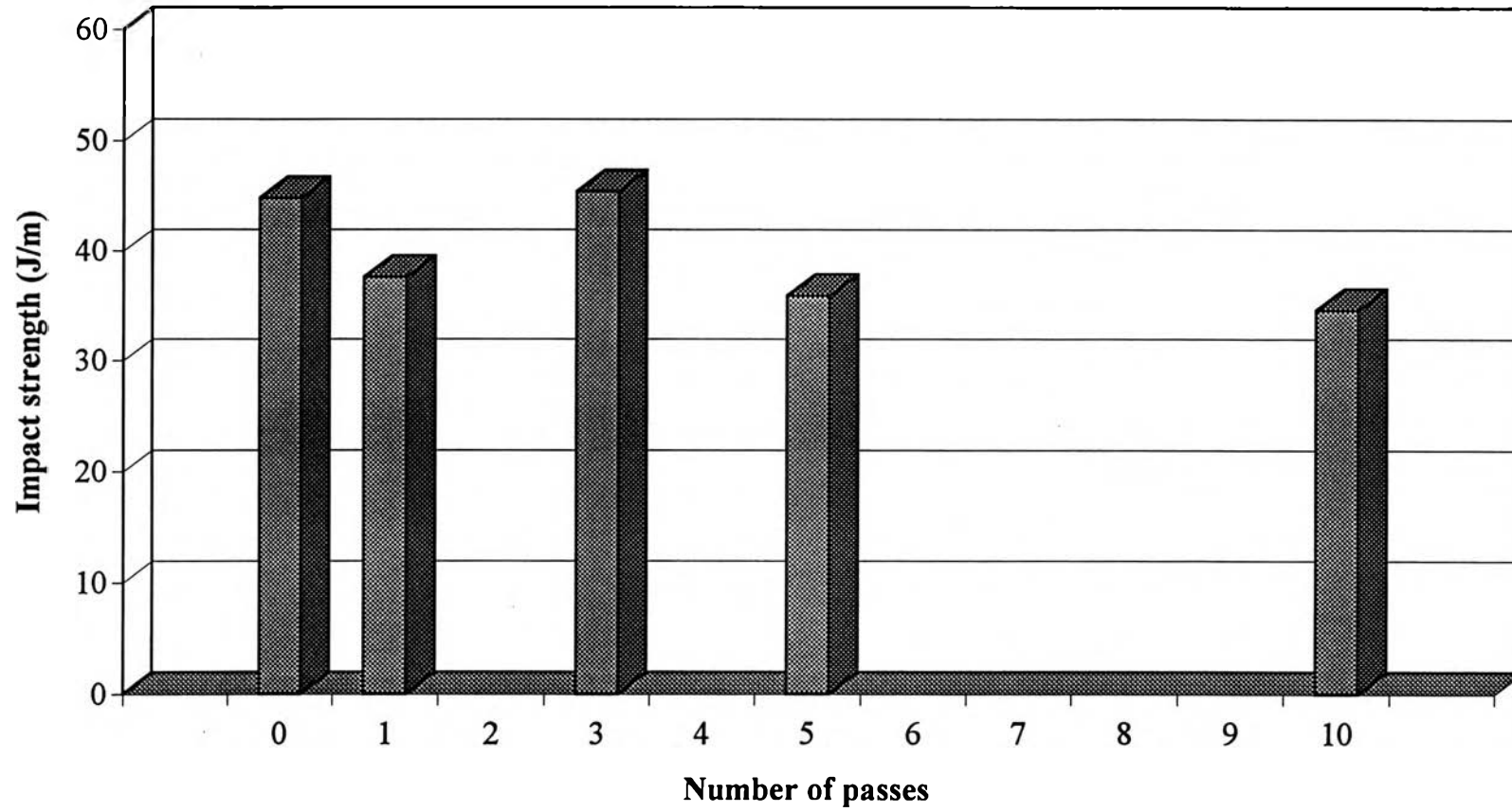


Figure 3.15 The impact strength of reprocessed polyetherimide

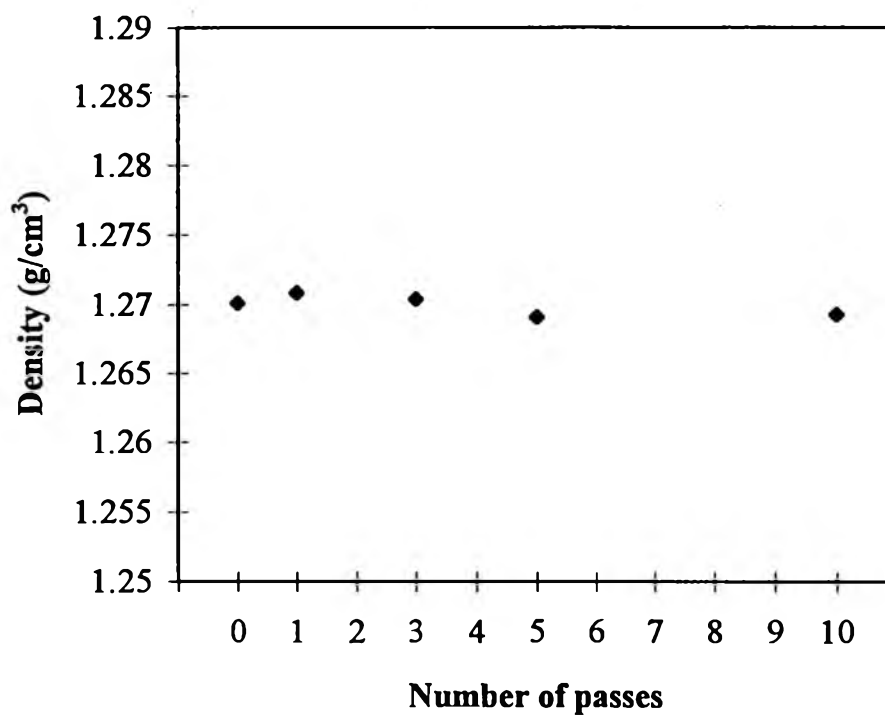


Figure 3.16 The density of reprocessed polyetherimide.

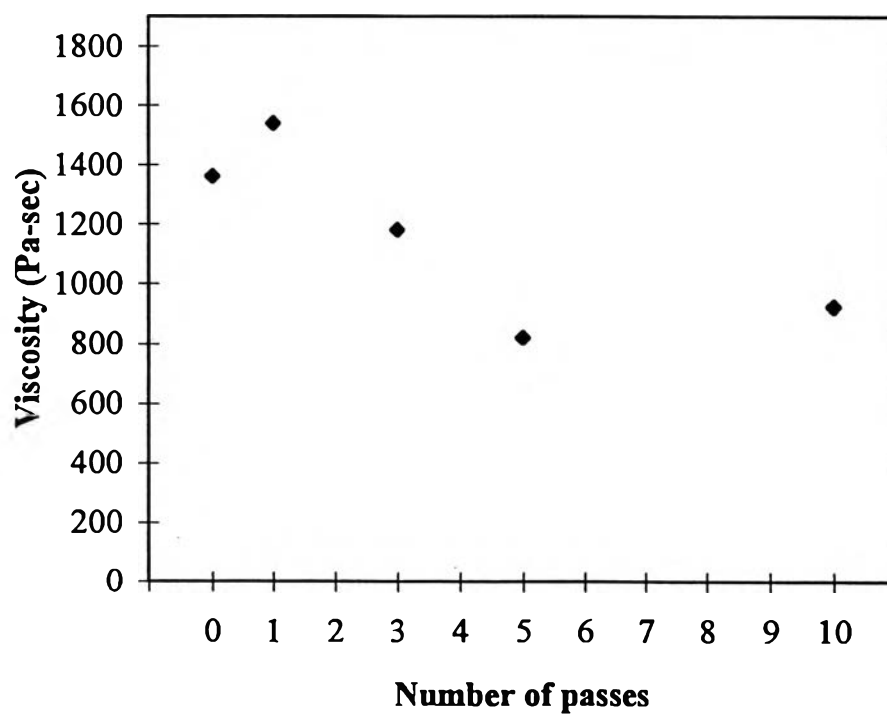


Figure 3.17 The viscosity of reprocessed polyetherimide at shear rate 50.6 sec⁻¹.

orient in such a way as to improve the mechanical properties. This is an oriented amorphous not crystalline [WARD, 1983].

Physical crosslinks due to entanglements will restrict molecular flow by causing the formation of temporary net work [MARGOLIS, 1985 ; BRYDSON, 1989]. As seen in figure 3.16 and 3.17, the density decreased after the first pass of reprocessing while the viscosity increased.

After reprocessing the mechanical strength slightly dropped and the viscosity increased. These results indicated the degradation of the material after reprocessing.

Shriver et.al. (1994) studied the reprocessing of Polycarbonate which is an amorphous polymer. They reported that polymer degradation changes molecular structure which affect rheological and mechanical properties but it did not largely affect on the mechanical properties. This report can be compared with this work that the viscosity of PEI started to drop after the first pass of reprocessing which can indicate the degradation of the material. And the mechanical properties were affected by decreasing the tensile strength, the flexural strength and the impact strength.