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Effect of Feeding Rate on Plastic Extrudates

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Selected grades of low density polyethylene (LDPE) polystyrene (PS) were extruded in a laboratory extruder by varying the feeding rate at different revolutions per minute and temperatures. The mechanical properties of the extruded plastic sheets were determined. LDPE shows a marked variation in mechanical properties with feeding rate while PS shows a marginal change in mechanical properties with feeding rate. However, for both plastics there is a particular feeding rate in the starved region which results in maximum mechanical properties.

Keywords: Low density polyethylene; polystyrene; feeding rate; extrusion; starved feeding

INTRODUCTION

In a conventional extruder, the extrusion rate is a function of the screw geometry for a given operating conditions [1]. However if the rate of solid-feed and hence the output rate could be made an independent operating variable, there are many advantages that can be obtained [2]. Nichols and Kruder [3] have listed the potential advantages of starve-feed metering.

Their results revealed that the screw torque requirement under starved condition is considerably less [4] compared to normal operation.

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This imparts greater versatility in extruder operation [5]. For example tough materials requiring a high screw torque capacity can be successfully handled with the same screw under starved conditions [6].

Because of the high viscosity [greater than $100\,N.S/m^2$] that is characteristic of polymer melts, a significant amount of viscous heat can be generated in flows that are subjected to high shear rates in extrusion [7]. Moreover, polymers have low thermal conductivities ensuring that high shear operations result in an increase in the temperature of the polymer. Because polymers have limited thermal stabilities, extrusion is limited to low shear operations or regions of limited high shear as in starved extrusion. Such limited high shear regions usually involve the flow of a thin polymer melt over a large surface area for maximum heat transfer and thereby resulting in maximum uniform mixing as shown by Spencer and Wiley [8]. This was later verified by Mohr, Saxton and Jepson for mixing in extruder [9]. Erwin showed that elongational flow can be more effective than shear flow for maximising mixedness in a given time frame as in starved extrusion [10].

In starved extrusion, the effective metering depth of the screw is reduced and it results in improvement in melting performance, due to the increase in rotational speed of the screw for the same screw rotation time [11]. Edwards *et al.* [12, 13] showed that the degree of mixing produced in the melting zone is more significant than that in the metering zone as in starved extrusion. The theory of reorientation as a mechanism of mixing in extrusion sections has been assessed by Erwin, Ng, Shah and Bigio *et al.*, found that it is more pronounced in starved extrusion [14–17]. Thus starved feeding is likely to result in reduced mechanical breakdown due to uniform mixing, better thermal homogenity and preferential orientation of the molecules due to comparative decrease in melt temperature [18] which may give rise to improved mechanical properties. The objective of this work is to determine the effect of feeding rate on the mechanical properties of low density poly ethylene and polystyrene extrudates.

EXPERIMENTAL

Materials

Low Density Polyethylene (LDPE): (Indothene FS 300 supplied by IPCL Baroda): Melt index 6.0 g/10min., density $0.922\ gm/cm^3$.

Polystyrene(PS): General purpose grade (polystron-678 SFI) supplied by M/s. Polychem. Ltd.; Bombay).

PREPARATION OF TEST SAMPLES

Experimental work was done on a laboratory extruder attached to a Brabender plasticorder model PL 2000 with an L/D ratio of 25 and a compression ratio of 2 and provided with a feeding roll. Two widely used plastics viz: LDPE and PS were selected for the study.

The feeding rates were adjusted by changing the dimensions of the feed gap at the bottom of the hopper and measured by the rate of output of the extrudate. The compounds were extruded at varying feeding rates mainly in the starved feeding region at 20, 40, 60 and 80 rpms and at different temperatures and the corresponding torque values were noted. The dumb-bell specimens were cut out of the extruded sheet for tensile testing. The tensile properties of the extrudates were measured using a Zwick universal testing machine model 1445, both in the extrusion and in its transverse directions at an extension rate 50 mm/min. as per ASTM D 412 (1980). The DSC curves of the starve and flood fed LDPE and PS samples were taken on a Perkin-Elmer DSC-7 model at a heating/cooling rate 10°C/min. under Nitrogen atmosphere as per ASTM D 3417 (1988). The density of the extruded sheets was measured according to ASTM D 792. The viscosity of the solutions of certain samples of LDPE and PS was determined using a Brookfield viscometer according to ASTM D 1084. The tensile fracture surfaces of few typical samples of LDPE and PS were examined using a scanning electron microscope of model JEOL JSM 35C to study the mode of failure.

RESULTS AND DISCUSSION

Figure 1 shows the variation of torque with feeding rate for LDPE at 180°C and PS at 220°C at different rpms and Figure 2, the variation of torque with feeding rate at different temperatures. The figures show the torque required for extrusion can be substantially brought down by operating in the starved region or employing higher temperatures.

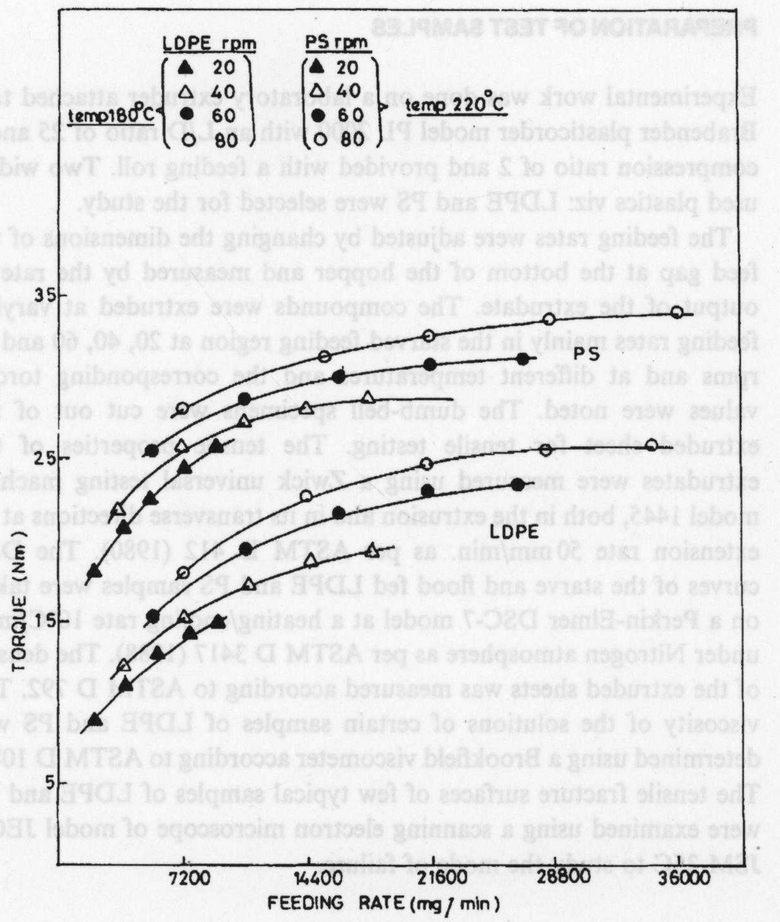

FIGURE 1 Effect of feeding rate on the torque values of LDPE and PS at different rpms.

Figure 3 shows the variation of tensile strength with feeding rate at different rpms for LDPE at a temperature of 180°C and PS at a temperature of 220°C. It is found that irrespective of rpm the tensile strength initially increases with feeding rate, reaches a maximum and thereafter decreases. This shows that for a given shear rate and temperature, there is a particular feeding rate in the starved region which results in maximum tensile strength. This is possibly due to the

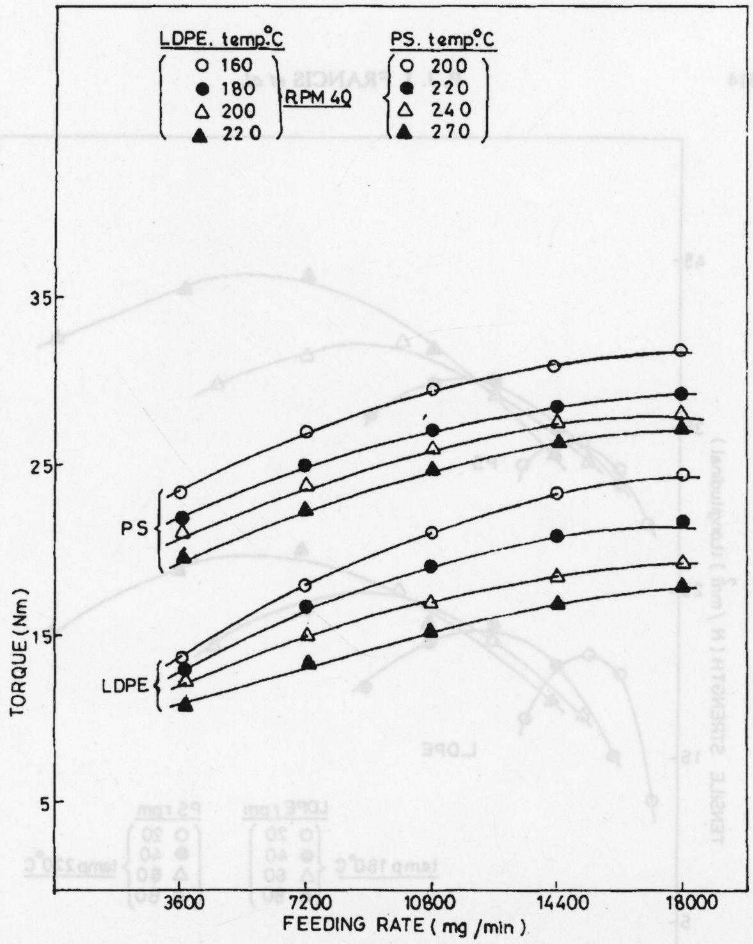

FIGURE 2 Effect of feeding rate on the torque values of LDPE and PS at different temperatures.

improved uniformity in temperature and better homogenity of the compounds than in normal feeding [19]. Further, lower shear break down and preferential orientation (more in the case of crystalline plastics like LDPE rather than amorphous plastics like PS [20]) of the molecules may be other reasons for the higher tensile strength at this feeding rate. The preferential orientation effect is clearly seen from the large

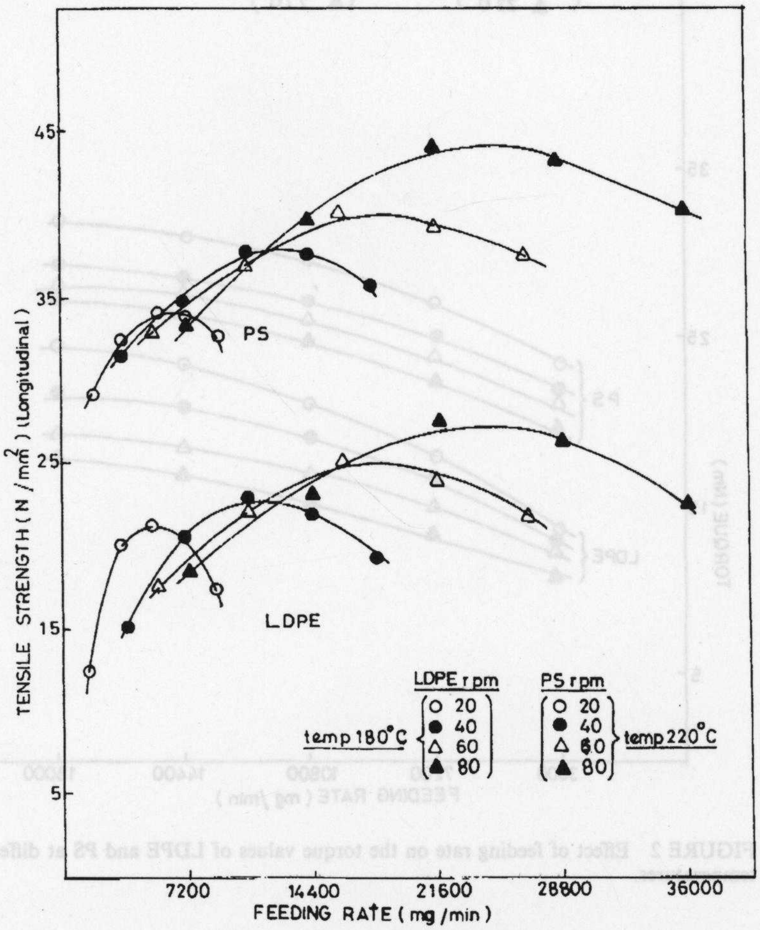

FIGURE 3 Effect of feeding rate on the tensile strength of LDPE and PS at different rpms in longitudinal (extrusion) direction.

differences between the tensile strength measured in the longitudinal (extrusion) and transverse directions in this case (Figs. 3 and 4).

Figures 5 and 6 show the variation in elongation at break of LDPE and PS with feeding rate in the longitudinal (extrusion) and transverse directions at different rpms. As in the case of tensile strength unimodel curves are obtained for each rpm. This further shows the efficiency of the starved extrusion in getting maximum physical properites.

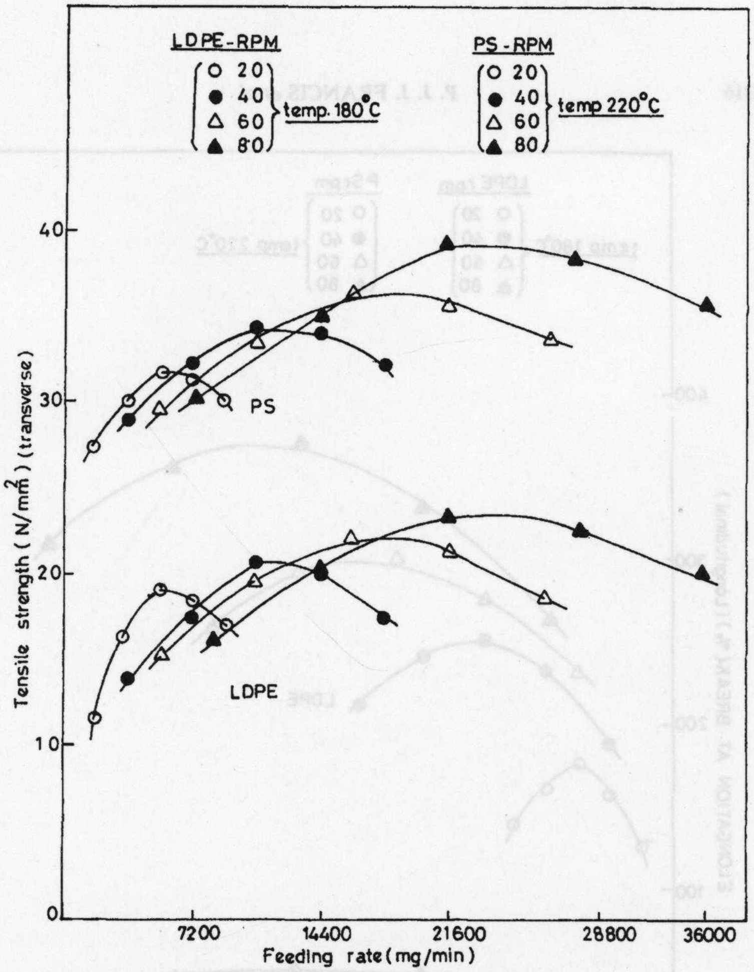

FIGURE 4 Effect of feeding rate on the tensile strength of LDPE and PS at different rpms in transverse direction.

Figures 7 and 8 show the variation in tensile strength of LDPE and PS with feeding rate at different temperatures at a fixed rpm. The tensile strength improves with temperature when the temperature is raised from 160°C to 200°C in the case of LDPE and from 200°C to 240°C in the case of PS showing that deterioration due to thermal degradation is not serious in this range. This result is expected since PS

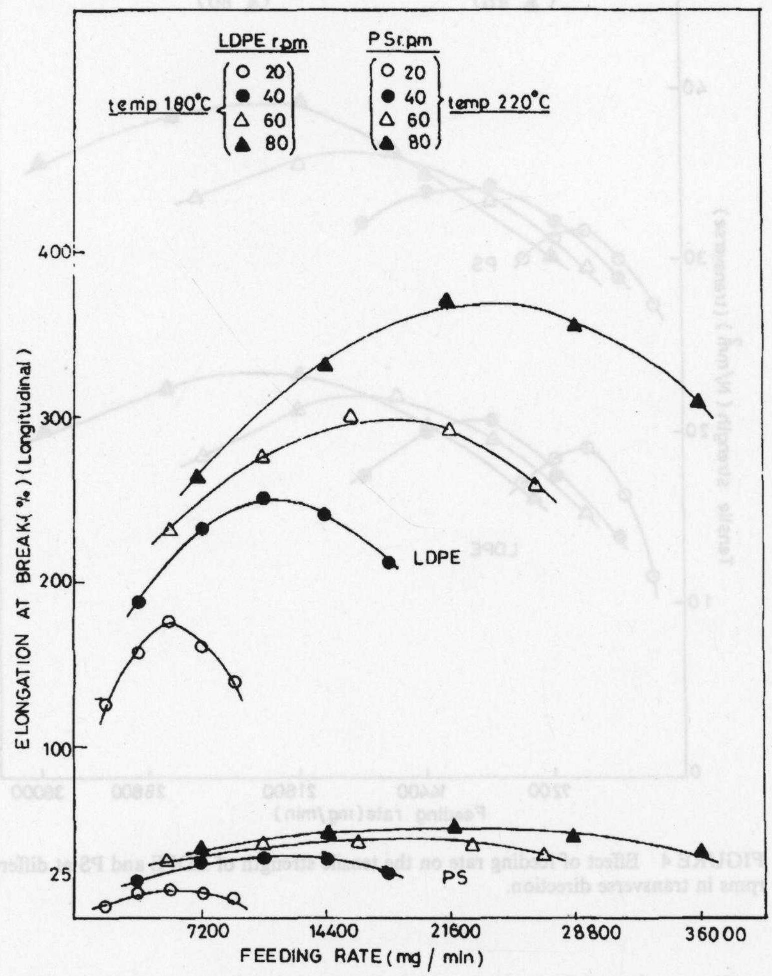

FIGURE 5 Effect of feeding rate on the elongation at break of LDPE and PS at different rpms in logitudinal (extrusion) direction.

is more thermally stable than LDPE [21]. But the strength at 220°C is less than at 200°C in the case of LDPE and the strength at 270°C is less than at 240°C in the case of PS showing the onset of degradation. At every temperature, the strength increases with feeding rate, reaches a maximum and decreases thereafter. As before, the maximum occurs just below the flood feeding point in the range 160 – 200°C and further

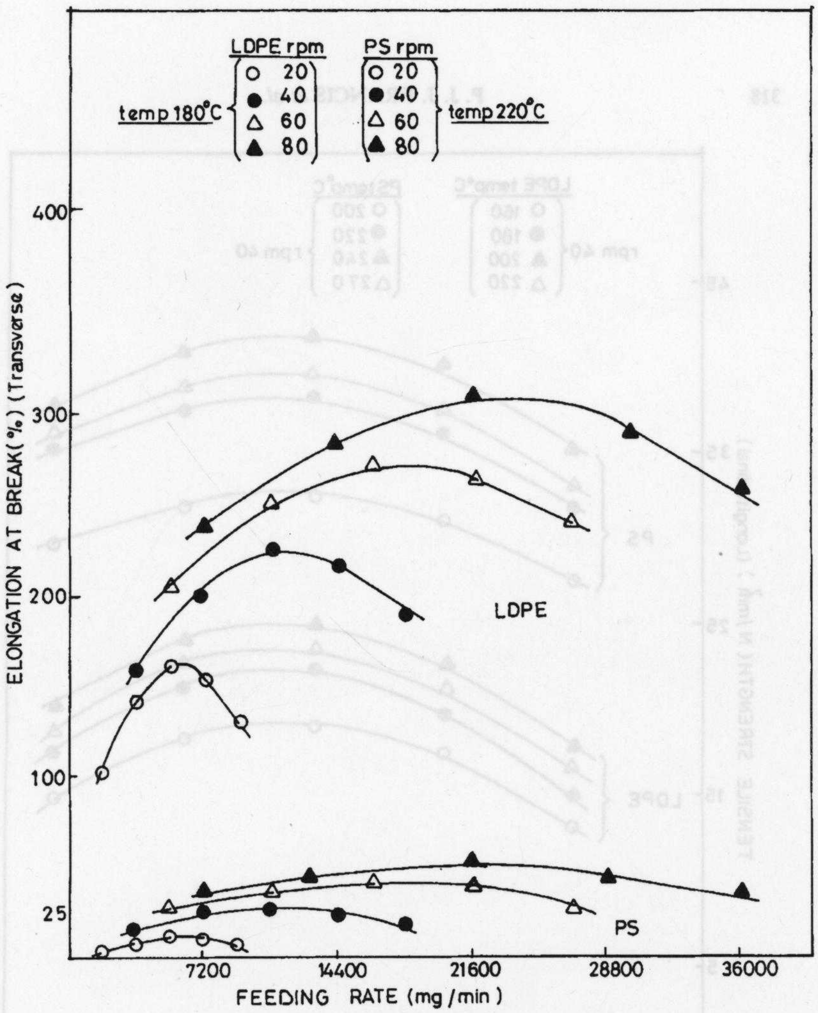

FIGURE 6 Effect of feeding rate on the elongation at break of LDPE and PS at different rpms in transverse direction.

down at 220°C in the case of LDPE and 200–240°C and further down at 270°C in the case of PS.

Figures 9 and 10 show the variation in elongation at break with feeding rate at different temperatures at a fixed rpm in the longitudinal

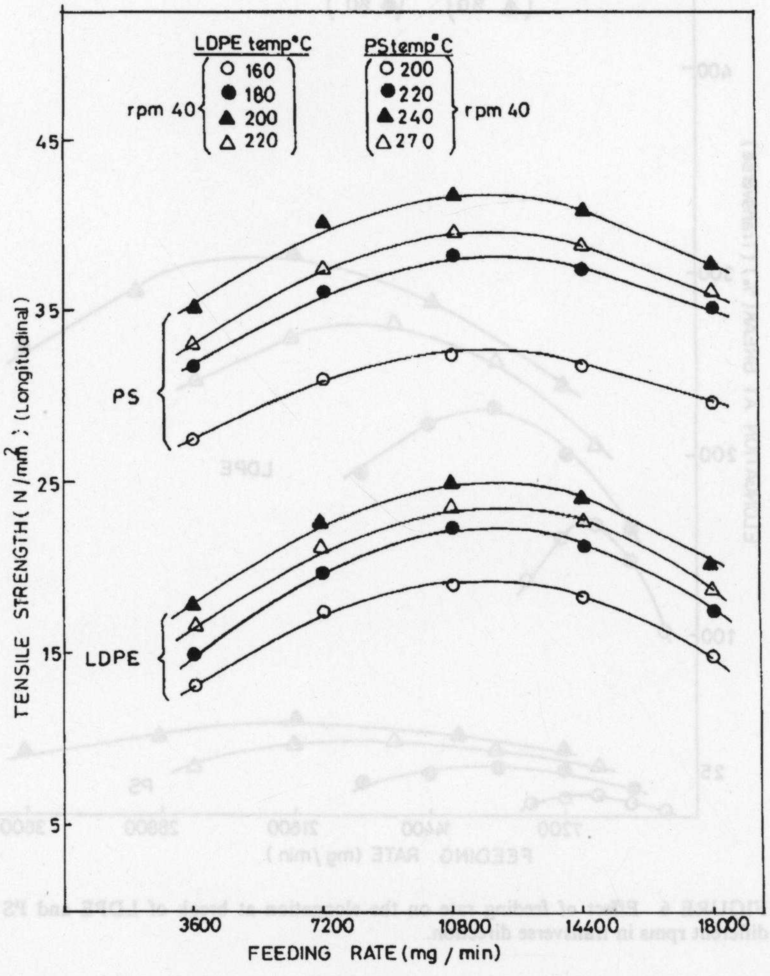

FIGURE 7 Effect of feeding rate on the tensile strength of LDPE and PS at different temperatures in longitudinal (extrusion) direction.

and transverse directions of LDPE and PS. The behaviour is more or less similar to those of the variations of the tensile strength.

Figures 11 and 12 show the DSC curves of the starve fed and flood fed samples of LDPE and Figures 13 and 14, the respective DSC curves of the corresponding samples of PS. It is observed that degree of crystallinity [22] in the starve fed sample is marginally higher than

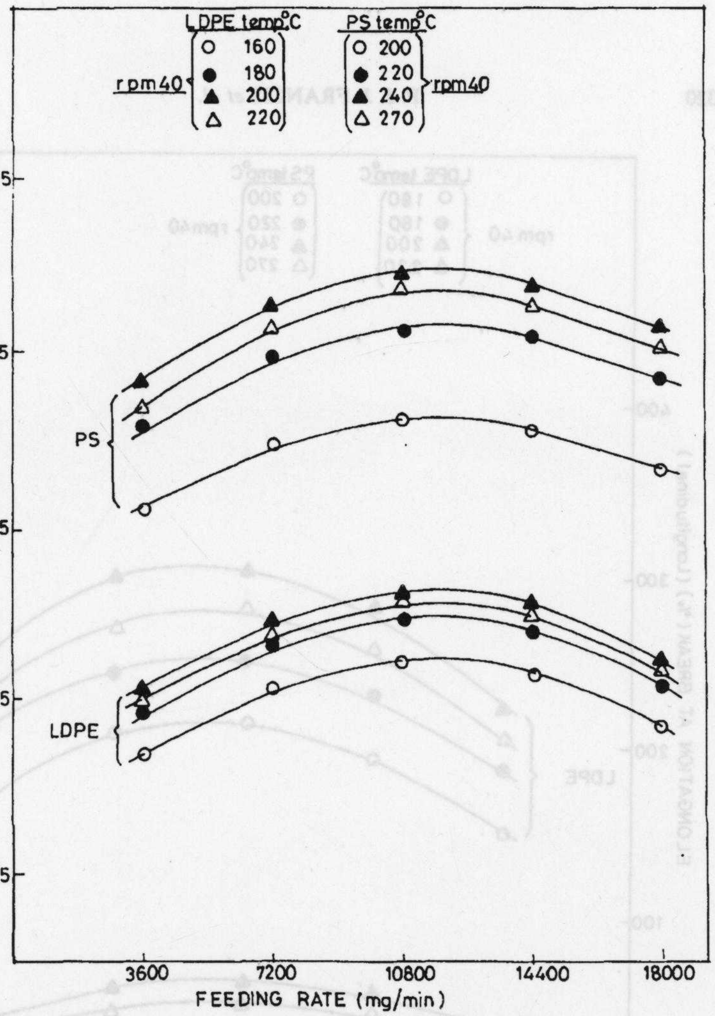

FIGURE 8 Effect of feeding rate on the tensile strength of LDPE and PS at different temperatures transverse direction.

that of the flood fed samples as seen from the ▲H value is higher for the starve fed sample. This is probably due to the more uniform temperature and shear history to which the compound was subjected to in the starved extrusion than in the normal extrusion.

Table I shows the variation in density of selected samples of LDPE and PS. It may be observed that the samples which give the maximum

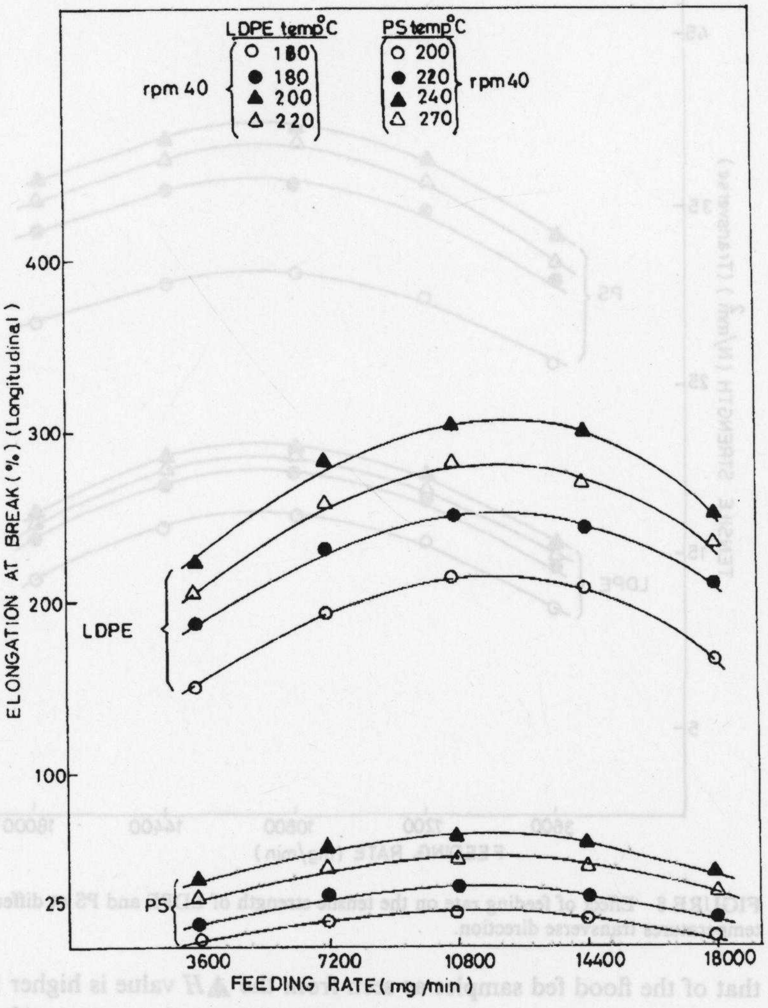

FIGURE 9 Effect of feeding rate on the elongation at break of LDPE and PS at different temperatures in longitudinal (extrusion) direction.

physical properties show the maximum density indicating that there can be minor variations in the percentage crystallinity [23] with the feeding rate. LDPE, being a crystalline plastic, shows marked variations while PS, being an amorphous plastic, shows only minor variations. Table I also shows the viscosity of the solutions of LDPE

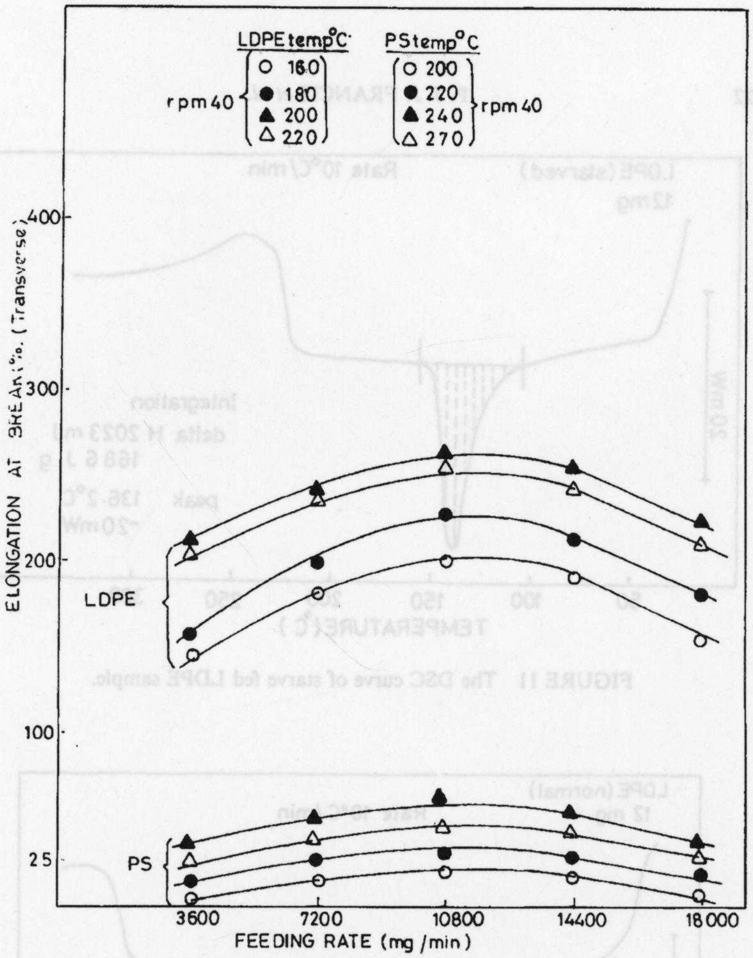

FIGURE 10 Effect of feeding rate on the elongation at break of LDPE and PS at different temperatures in transverse direction.

and PS. It may be observed that starve feeding results in higher viscosities of the solutions due to lower mechanical breakdown.

The tensile fracture surfaces (both starve fed and flood fed samples) of LDPE and PS are shown in Figure 15(a, b, c and d). It is observed that in starve fed samples, there is a uniform particle distribution in a

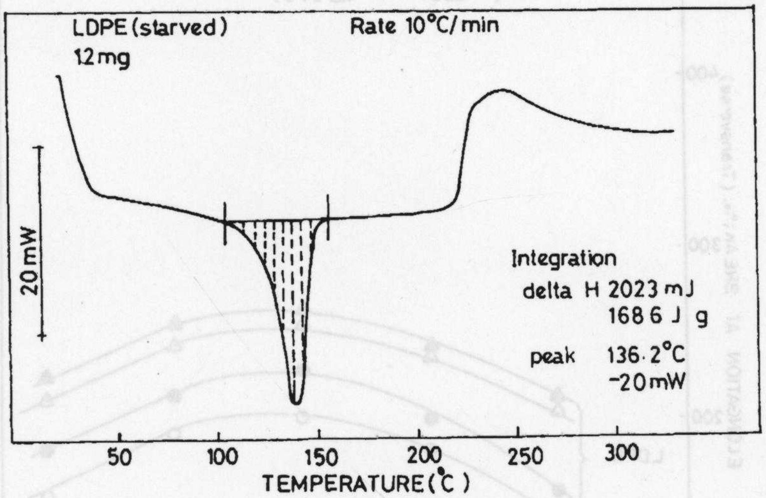

FIGURE 11 The DSC curve of starve fed LDPE sample.

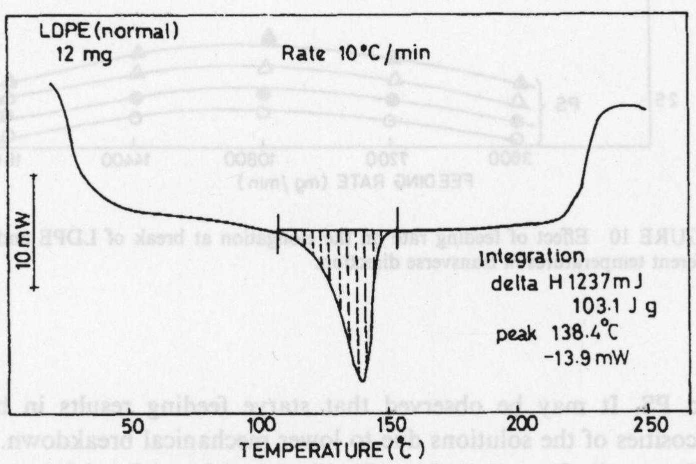

FIGURE 12 The DSC curve of flood fed LDPE sample.

particular orientation and this may be due to higher amount of interparticle bonding which in turn due to more uniform shear/temperature distribution.

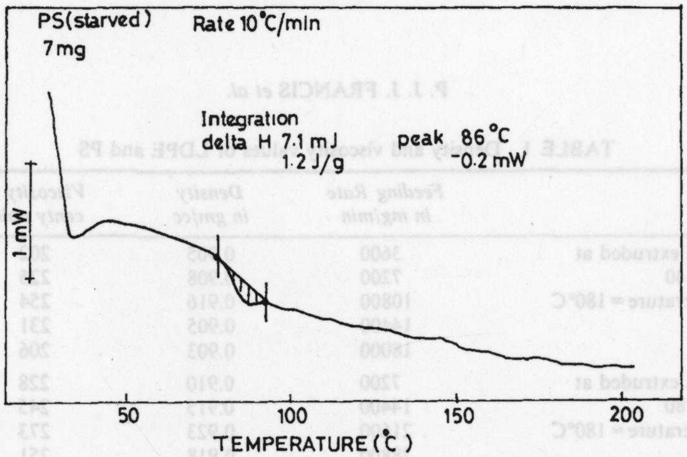

FIGURE 13 The DSC curve of starve fed PS sample.

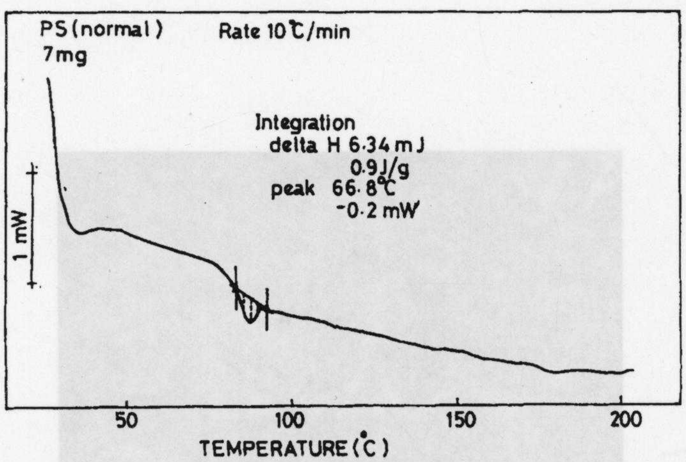

FIGURE 14 The DSC curve of flood fed PS sample.

TABLE I Density and viscosity values of LDPE and PS

	Feeding Rate in mg/min	*Density in gm/cc*	*Viscosity in centy poise*
LDPE extruded at	3600	0.905	202
rpm = 40	7200	0.908	225
Temperature = 180°C	10800	0.916	254
	14400	0.905	231
	18000	0.903	206
LDPE extruded at	7200	0.910	228
rpm = 80	14400	0.915	245
Temperature = 180°C	21600	0.923	273
	28800	0.918	251
	36000	0.914	235
PS extruded at	3600	1.065	460
rpm = 40	7200	1.069	480
Temperature = 220°C	10800	1.073	512
	14400	1.067	495
	18000	1.062	490
PS extruded at	7200	1.071	520
rpm = 80	14400	1.078	542
Temperature = 180°C	21600	1.086	555
	28800	1.070	514
	36000	1.067	503

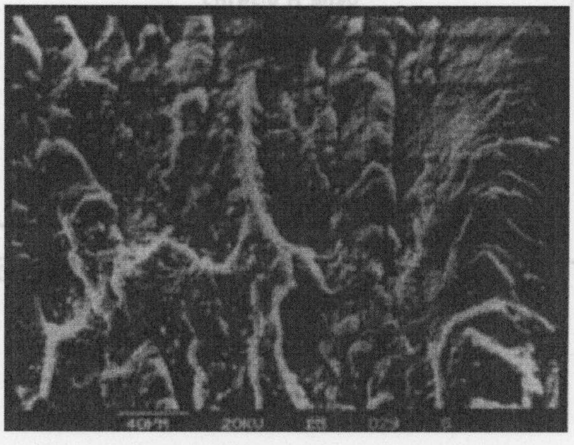

FIGURE 15(a) SEM micrograph of starve fed LDPE sample.

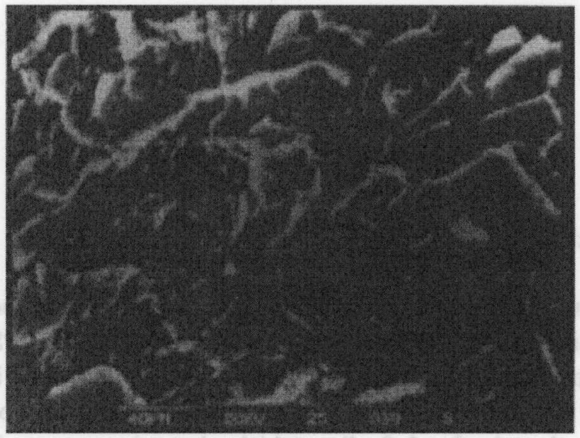

FIGURE 15(b) SEM micrograph of flood fed LDPE sample.

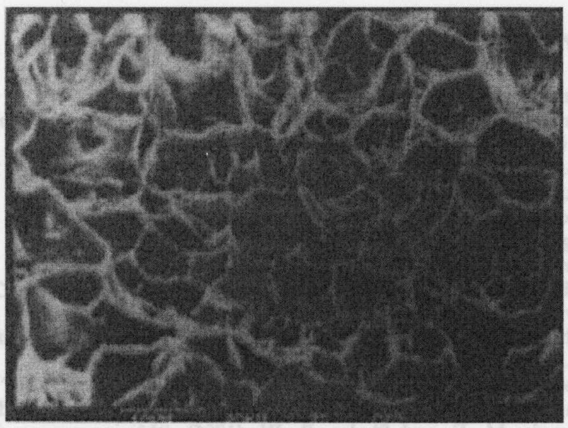

FIGURE 15(c) SEM micrograph of starve fed PS sample.

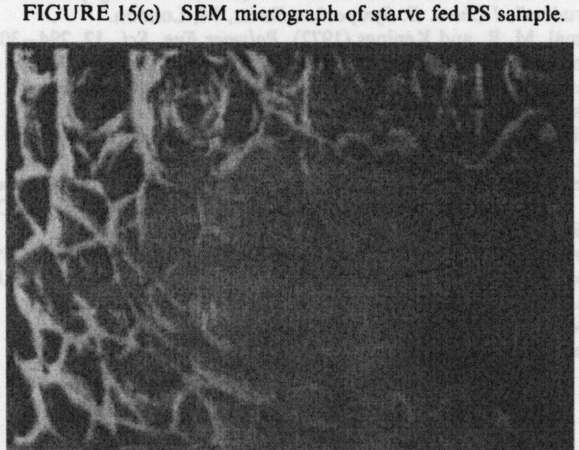

FIGURE 15(d) SEM micrograph of flood fed PS sample.

CONCLUSIONS

The study shows that starve feeding in respect of both a semi crystalline plastic, (LDPE) and an amorphous plastic, (PS) results in better mechanical properties than in flood feeding. This is obviously due to the more uniform shear/temperature distribution in starve feeding than in flood feeding which gives rise to marginally lower mechanical degradation and higher degree of crystallinity.

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