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CORRELATIONS OF SOME TENSILE PROPERTIES FOR VARIOUS GRADES OF LOW DENSITY POLYETHYLENE

R.R. Zahran and A.Y. Kandeil
College of Engineering, Qatar University,
Doha, State of Qatar.

ABSTRACT

The tensile properties of nine different grades of low density polyethylene were measured, and the relationships resulting from the combination of different pairs of properties were analyzed. It was found that some properties correlate well together, with a correlation coefficient better than 0.90. Such correlations will be useful in easily predicting the tensile properties of low density polyethylene. The FB grades exhibited the highest ultimate tensile strength and offset yield strength while their ductility and toughness were lowest when compared with the other grades. The MG12 and FD grades were of highest modulus of elasticity. The variation in a given property, for the nine grades, ranged from 40% for the ultimate tensile strength, up to 2.6 fold for the strain at break.

INTRODUCTION

The crystallization conditions, molecular weight, molecular weight distribution and chain branching have a great impact on the properties of low density polyethylene (LDPE). Chain branching has a predominant effect on the density of polyethylene [1,2]. Therefore, properties depending on crystallinity, such as modulus of elasticity, tear and tensile strength, hardness and yield point increase with density or with decreasing the amount of chain branching, whereas, toughness and ductility decrease under the same conditions. Also, as the molecular weight increases, so do the tensile strength, the tear strength and the softening temperature. The deformation behavior and such properties have been extensively analyzed in order to explain the observed behavior [1, 3-6]. The mechanical properties of LDPE are between those of rigid materials like polystyrene and limp plasticized polymers like vinyls. Many grades of LDPE are produced all over the world, each of which is suitable for a particular application. They are mainly used for extrusion of strong blown film for bags, blow molding containers, bottles, packing of foodstuffs and pharmaceuticals, cosmetic tubes, cable conduits etc.... .

The present work emphasizes the analysis of some tensile properties for nine different grades of LDPE produced by Qatar Petrochemicals Co. (QAPCO). The variations in the mechanical properties of the different grades are related to the morphological features of the polymer. Furthermore, a set of mathematical correlations between these properties is developed. Such correlations can be easily used to predict some tensile properties for the different grades of LDPE.

EXPERIMENTAL

The material used in the present investigation was Lotrène LDPE produced by QAPCO. Nine different grades were used, namely: FB3003, FB5005, FB5026, FA0234, FD0274, FD0374, FD0474, CD0230 and MG12. Some properties and various additives for the different grades, as supplied by the manufacturer, are listed in Table 1. Standard tensile specimens of the various grades were produced using injection molding. The samples were produced using an injection temperature of 150°C , an injection pressure of 160 kg/cm^2 and a die temperature of 25°C. The samples obtained were of a dog-bone shape with a gauge length of 65 mm, width of 12.6 mm and thickness of 3.1 mm.

Tensile testing was carried out using Lloyd Instruments materials testing machine linked to a remote microcomputer for data acquisition and analysis. The load was measured by a load cell 5 kN capacity, with an accuracy better than 1%, while the displacement was measured using an internal extensiometer with an accuracy better than 0.5% of the range set. A wide range of testing speed is available for tensile testing. Generally, the choice will influence the results [6,8]. No change in the elongation at break was observed for elongation rates in the range from 0.2 mm/min to 200 mm/min [9]. So, the speed of testing was 100 mm/min. Lloyd Data Analysis Package (DAP) was used to analyze the tensile properties from the load-extension diagrams. The following tensile properties were determined: ultimate tensile strength, modulus of elasticity, offset yield stress, strain at maximum load, strain at break and work done. Five samples were tested at the same conditions for each grade.

Table 1: Technical Data for Lotrène LDPE

Property	Unit	FB3003	FB5005	FB5026	FA0234	FD0274	FD0374	FD0474	CD0230	MG 12
Density at 23°C	g/cm^3	0.919-0.921	0.919-0.921	0.919-0.921	0.920-0.922	0.920-0.922	0.920-0.922	0.920-0.922	0.920-0.922	0.920-0.922
Melt flow index	g/10min	0.24-0.30	0.50-0.70	0.50-0.70	1.7-2.0	1.8-2.4	3.3-3.8	4.0-5.0	1.8-2.2	10.0-16.0
Antioxidant	Level	Nil	Nil	Nil	Present	Present	Present	Present	Nil	Present
Slip agent	Level	Nil	Nil	Low	Medium	Medium	Medium	Medium	Nil	Low
Antiblocking agent	Level	Nil	Nil	Nil	Medium	Medium	High	Medium	Nil	Low

Density measurements were carried out using pycnometry [2]. The densities of the samples were determined at 23°C in a 60:40 (volume ratio) isopropanol-water mixture.

RESULTS AND DISCUSSION

Typical stress-strain diagrams were produced from load-extension diagrams using the data acquisition and analysis package and are shown in Figure 1. In this case we have a poorly defined or perhaps absent yield point. Beyond the yield point, there is essentially a continuous increase in stress with strain, up to fracture. This phenomenon is commonly termed 'strain hardening' [7], and an offset yield will be used throughout the paper. The tensile properties for the different grades are summarized in Table 2. Each data point was calculated as the average of measurements on five different samples.

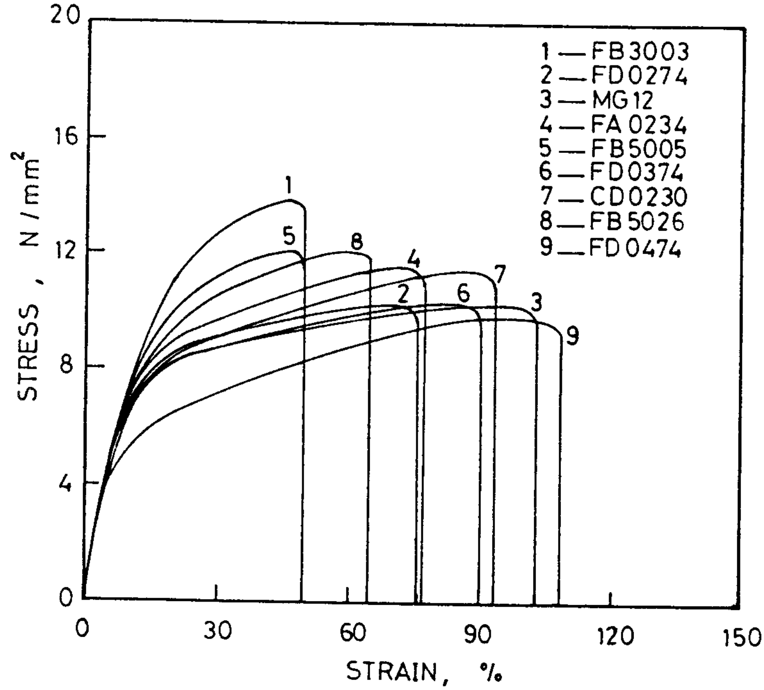

Fig. 1: Typical stress-strain curves for the nine grades of LDPE

Table 2 Typical Tensile Properties of the Different Grades of LDPE

Property / Grade	Ultimate tensile strength (MPa)	Strain at maximum load (%)	Strain at break (%)	Work done (N.mm)	Modulus of elasticity (MPa)	Offset yield stress (MPa)
FB 3003	14.31	43.79	47.54	15390	72.4	12.09
FB 5005	13.16	49.53	53.62	16220	61.23	11.12
FB 5026	12.50	55.65	62.11	18620	76.15	9.449
FA 0234	11.34	74.80	81.37	23380	66.23	8.785
FD 0274	11.13	73.96	80.12	23060	89.36	8.098
FD 0374	10.23	81.98	89.12	23350	91.88	7.258
FD 0474	12.01	109.9	123.4	32310	123.3	6.862
CD 0230	12.27	80.85	58.05	23030	85.05	8.489
MG 12	10.41	95.06	107.97	25710	95.52	7.598

Since the properties of polyethylene depend on its chemical composition as well as its microstructure, it is to be expected that some interrelationships between these properties exist. In what follows, an attempt will be made to correlate the various tensile properties of the different grades of LDPE. The correlation between the ultimate tensile strength and each of the modulus of elasticity, the offset yield stress, the strain at maximum load, the strain at break and the work done are shown in Figures 2 to 6. The mathematical correlations are plotted on each igure. It is interesting to note that all of

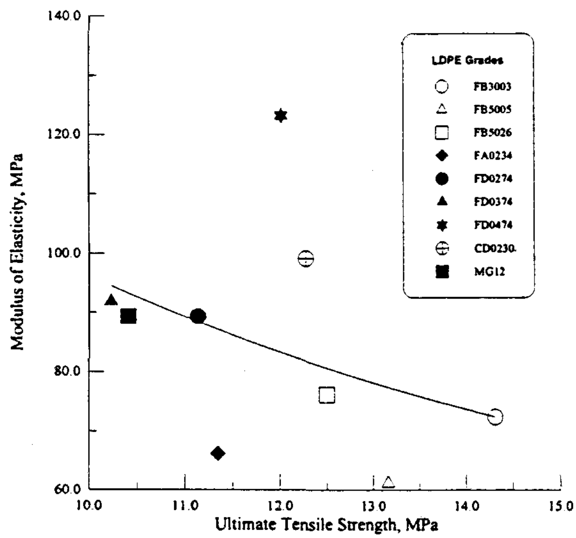

Fig. 2: Variation of the modulus of elasticity with the ultimate tensile strength for different grades of LDPE

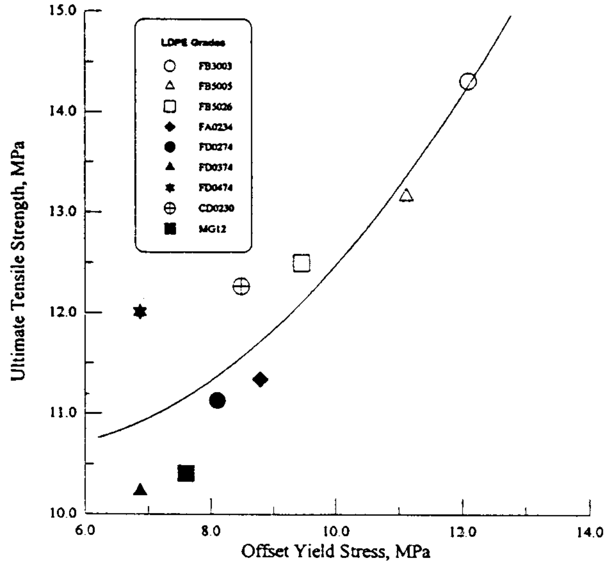

Fig. 3: **Dependance of the ultimate tensile strength on the offset yield stress for different grades of LDPE**

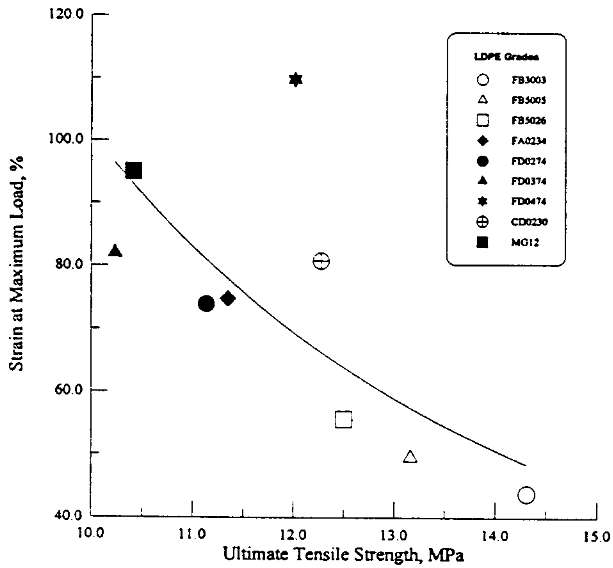

Fig. 4: **Relationship between the strain at maximum load and the ultimate tensile strength for different grades of LDPE**

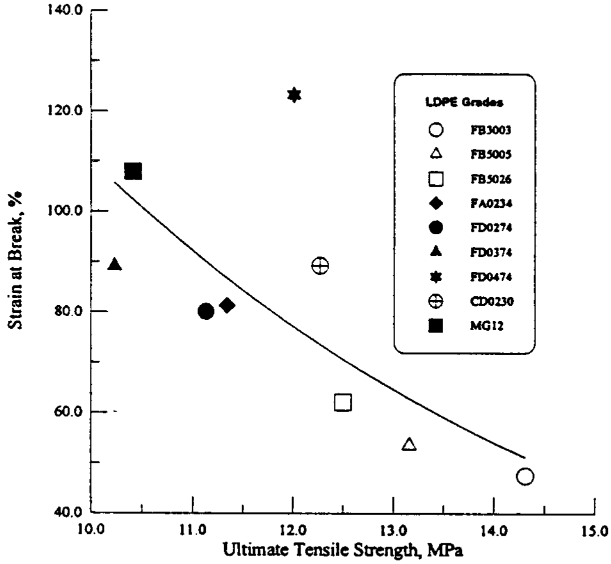

Fig. 5: Variation of the strain at break with the ultimate tensile strength for different grades of LDPE

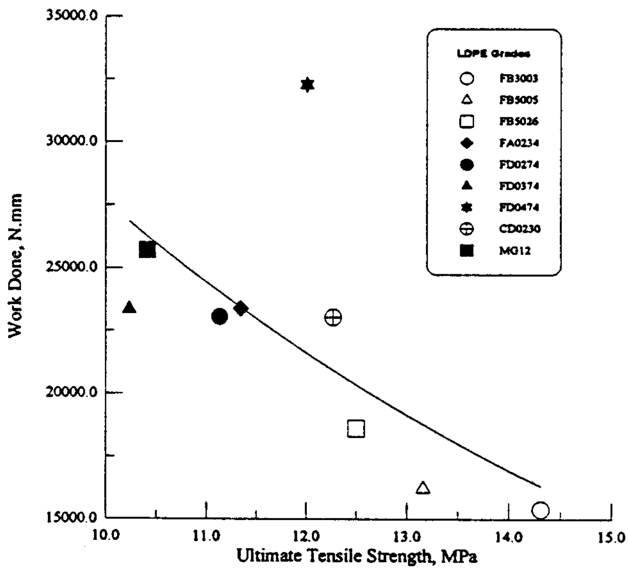

Fig. 6: Work done as a function of the ultimate tensile strength for different grades of LPDE

these properties are decreasing with the ultimate tensile strength, except for the offset yield stress. The mathematical correlations and the corresponding correlation coefficients are given in Table 3; they are obtained using least squares fitting. In general , correlations exist between the ultimate tensile strength and the other tensile properties, in particular, for the offset yield stress and the strain at break. The latter is in agreement with the general trend normally observed between the ultimate tensile strength and the ductility of the material. Figures 7 to 9 illustrate the relationships between the modulus of elasticity, strain at break and work done on one hand, and the strain at maximum load on the other hand. The general almost a linear increase in the tensile properties with the strain at maximum load is observed.

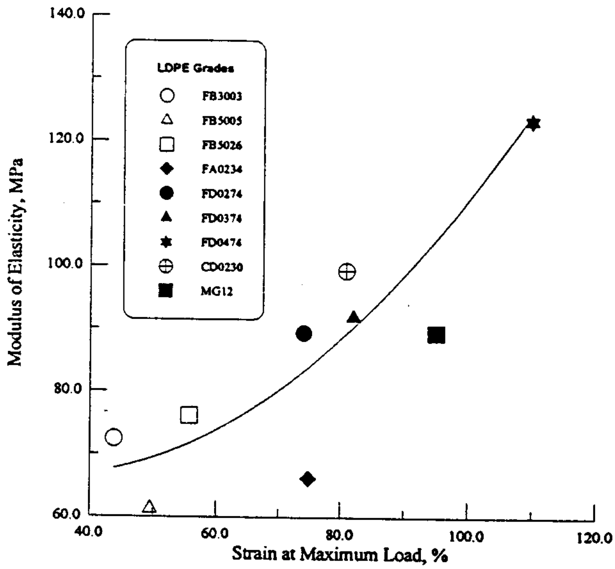

Fig. 7: Dependence of the modulus of elasticity on the strain at maximum load for different grades of LDPE

Table 3: Mathematical Correlations Between Tensile Properties

Independent Variable (x)	Dependent Variable (y)	Relation y(x)	Correlation Coefficient
Ultimate tensile strength	Modulus of Elasticity	*log* y = -0.7959*log*x + 6.40041	0.1284
Ultimate tensile strength	Strain at max. stress	*log* y = -2.0549*log*x + 9.34687	0.5421
Ultimate tensile strength	Strain at break	*log* y = -0.17764x + 6.7484	0.5502
Ultimate tensile strength	Work done	y =93557.6 *exp*(-0.12205x)	0.4771
Strain at max. Stress	Modulus of Elasticity	$y = 76.2043 - 0.6136x - 0.00957x^2$	0.8056
Strain at max. Stress	Strain at break	*log* y = 1.02197*log* x - 0.001069	0.9983
Strain at max. Stress	Work done	$y = 8115.61 + 136.849x + 0.73785x^2$	0.9804
Offset yield Stress	Ultimate tensile strength	$y = 13.9357 - 1.03657x + 0.08833x^2$	0.7615
Offset yield Stress	Modulus of Elasticity	*log* y = -0.90444*log*x + 6.38499	0.6232
Offset yield Stress	Strain at max. stress	*log* y = -1.53273*log*x + 7.58222	0.9157
Offset yield Stress	Strain at break	*log* y = -1.57859*log*x + 7.77727	0.9079
Offset yield stress	Work done	*log* y = -1.15379*log*x + 12.4886	0.8909
Strain at break	Modulus of Elasticity	$y =67.2587 - 0.29737x + 0.00617x^2$	0.8103
Strain at break	Work done	$y =6790.1 + 166.8882x +0.30973x^2$	0.9805
Modulus of Elasticity	Work done	$y = 17014.5 - 96.6567x + 1.78151x^2$	0.7271

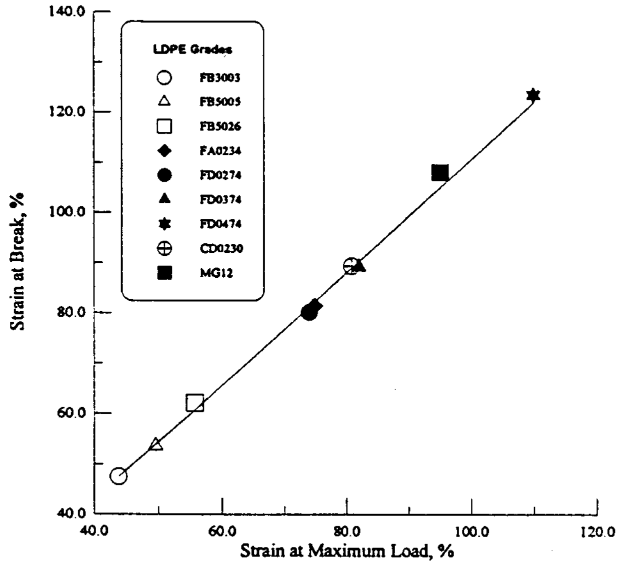

Fig. 8: **Relationship between the strain at break and the strain at maximum load for different grades of LDPE**

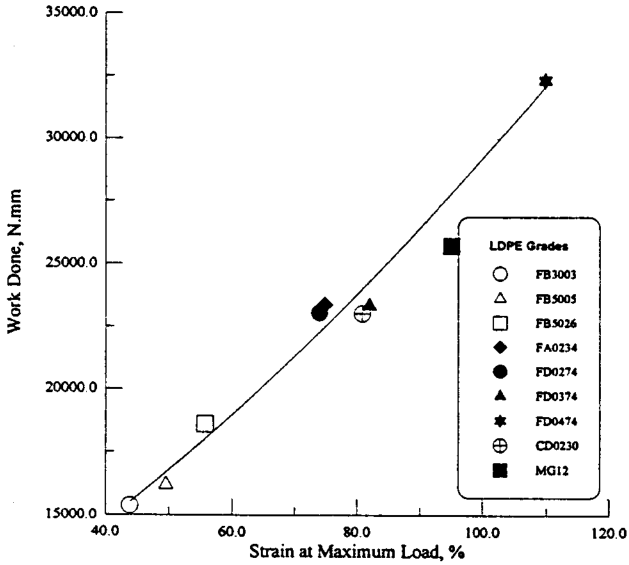

Fig. 9: **Variation of the work done with the strain at maximum load for different grades of LDPE**

The dependence of the tensile properties on the offset yield stress for the different grades is shown in Figures 10 to 13. The modulus of elasticity, the strain at maximum load, the strain at break and the work done decrease with the offset yield stress. A poor correlation was observed between the strain at break and the modulus of elasticity, as seen in Figure 14. However, Figure 15 shows better correlation between the work done and the strain at break. The correlation coefficients are 0.455 and 0.655, respectively. Generally, the work done seems to increase with the modulus of elasticity, as shown in Figure 16.

It is of interest to note that the FB grades have relatively high ultimate tensile strength and high offset yield stress while they have relatively lower modulus of elasticity, lower ductility, lower strain at maximum load and lower toughness, when compared to the FD grades, FA 0234 and MG 12. Grade CD 0230 has an intermediate level of all tensile properties. Based on the previous observations, the FB grades possesses the lowest values for: strain at maximum load, strain at break and work done. This is anticipated, since they contain no slipping agent as seen from able 1; also they are of

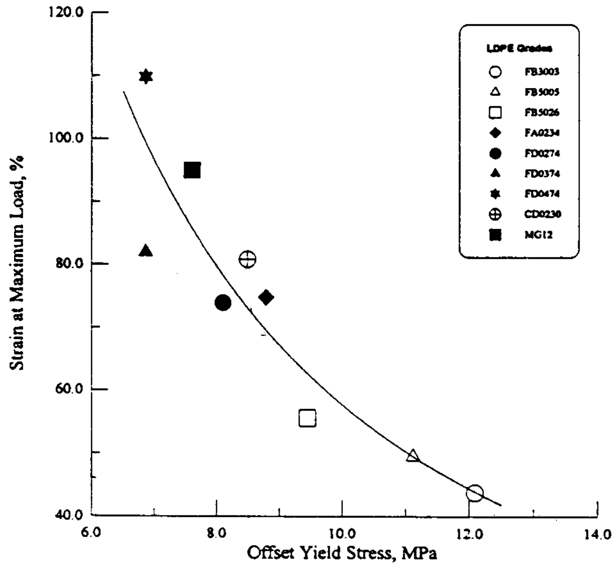

Fig. 10: Effect of the offset yield stress on the modulus of elasticity for different grades of LDPE

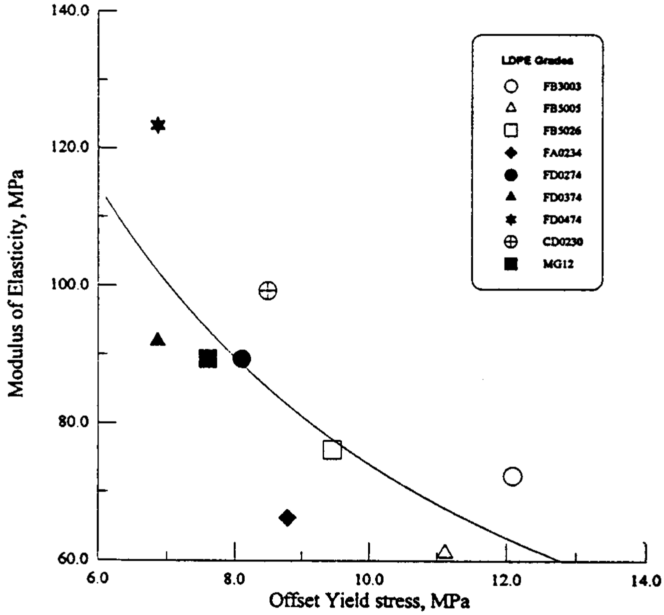

Fig. 11: Dependence of the strain at maximum load on the offset yield stress for different grades of LDPE

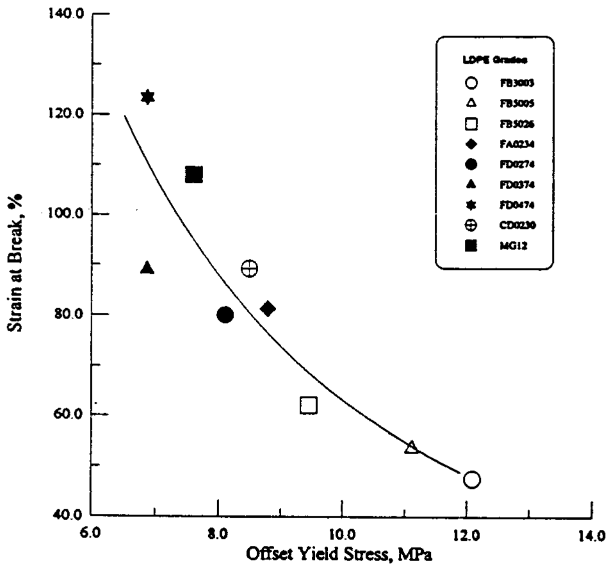

Fig. 12: Variation of the strain at break with the offset yield stress for different grades of LDPE

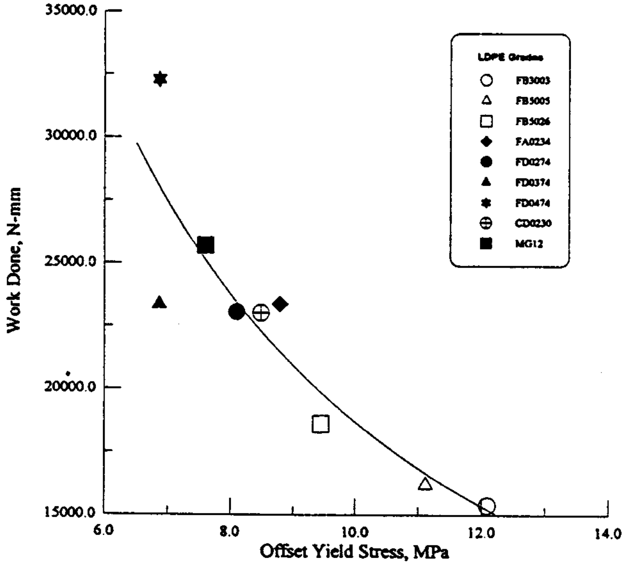

Fig. 13: Relationship between the work done and the offset yield stress for different grades of LDPE

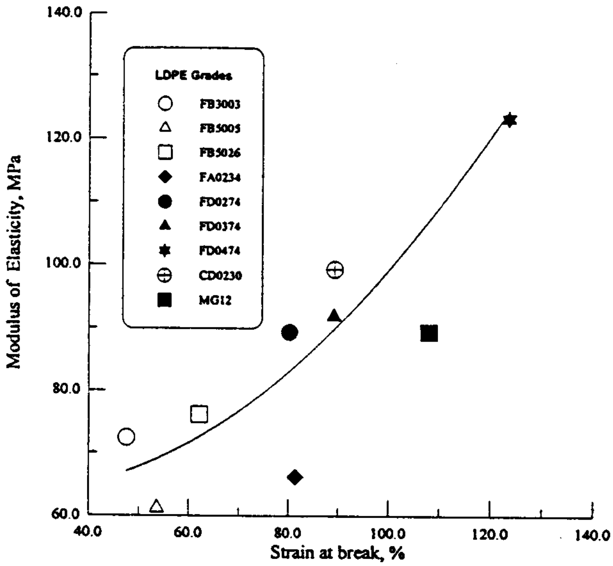

Fig. 14: Variation of the modulus of elasticity with the strain at break for different grades of LDPE

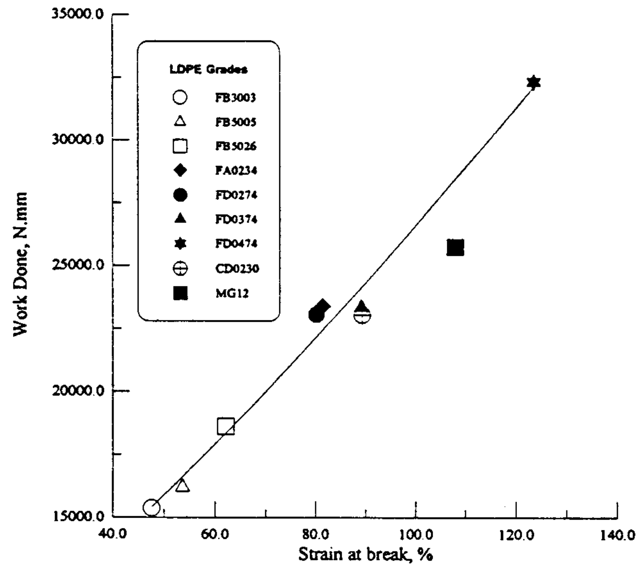

Fig. 15: Dependence of the work done on the strain at break for different grades of LDPE

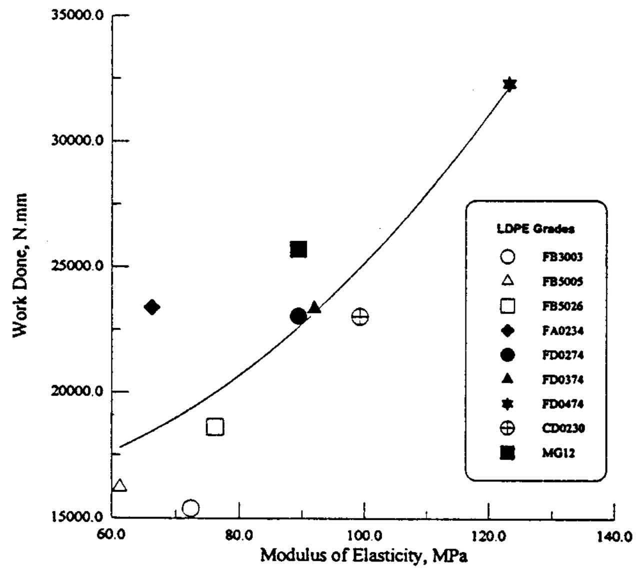

Fig. 16: Variation of the work done with the modulus of elasticity for different grades of LDPE

relatively higher molecular weights as seen from their melt indices. On the other hand, the grades containing slipping agent (FD series and FA series) show relatively higher strain at maximum load, strain at break and work done. Density measurements have shown that the latter grades are of higher density, as seen from Table 4. Because of their higher density (and therefore, higher crystallinity) they are expected to show higher modulus of elasticity. Such an expectation coincides with experimental observations as seen in Figure 2. The high content of the antiblock agent in grade FD0374 (Table 1) can cause this grade to be of the lowest offset yield strength, as shown in Figure 3.

Table 4: Density at 23°C for the Various Grades of LDPE

Grade	FB3003	FB5005	FB5026	FA0234	FD0274	FD0374	FD0474	CD0230	MG12
Density g/cm³	0.9194	0.9201	0.9200	0.9219	0.9219	0.9220	0.9223	0.9220	0.9206

CONCLUSIONS

The various grades of LDPE have different mechanical properties that are affected by the morphological structure and the additives included. Some properties correlate well together with a correlation coefficient better than 0.90; such as the ultimate tensile strength with each of the strain at break, the strain at maximum load and the offset yield stress. Such mathematical correlations are beneficial in predicting the various tensile properties of LDPE, and therefore, may prove to be practical in selecting a particular grade for a given application with target mechanical properties.

The FB grades exhibit the highest ultimate tensile strength and offset yield strength while they exhibit the lowest ductility and toughness. The MG12 and FD grades are of higher modulus of elasticity.

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