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QUALITATIVE CONNECTION BETWEEN SOLID PARTICLE EROSION AND MECHANICAL PROPERTIES OF ELASTOMERS

F. A. BASSILI *

ABSTRACT

Elastomers have good erosion resistance. They are used in coating materials suceptible to solid particle erosion, such as fibre glass reinforced polymers. Erosion parameters of the attacking solid particles affecting erosion resistance of elastomers are reviewed . A model connecting erosion resistance and mechanical properties of elastomers is suggested and experimentaly verified . A constant is proposed in the model and is explained in light of parameters of the erosive particles . The model shows that selection of an elastomer with high erosion resistance is based on selection of an elastomer having a big product of fracture strength and strain. Further work is suggested on study of effect of thickness of the elastomer coat on erosion resistance of the coated material.

* Lecturer, University of Suez Canal, Faculty of engineering for Petrol and Mining, Suez, Egypt.

INTRODUCTION

Elastomers are of particular interest to engineering designers since they have many attractive properties including low density, low cost and good erosion and corrosion resistance compared with metals. Thin layer of an elastomeric material can be used to cover a surface of a material which has poor erosion resistance, to protect it against attacking solid particles and rain water (1,2). Erosion resistance is reciprocal of volume removed of a material by unit weight of errosive particles. It has been reported (1) that erosion resistance of the main rotor and blades of helicopter has improved by coating them with neoprene and polyurethane. The relative merits of bare stainless steel, neoprene and polyurethane for erosion resistance are about one to five to ten respectively. In Rolls Royce Ltd. (3), an elastomeric material is used for coating concave surfaces of low temperature composite blades of the eoro-engine RB. 162 . Improvement obtained in erosion resistance is about forty times the erosion resistance of the bare composite. A similar result (4) is obtained when fibre glass reinforced polymer coated with thin layer of polyurethane was investigated in an erosion test.

In an early work (4) the author investigated effect of different erosion parameters on erosion of elastomers. The following is a short note of some of the author's work on erosion of elastomers to which the present work is extended.

Relationship between erosion rate ε of an elastomeric polymer (polyurethane) and velocity of erosive particles V is ,

$$\varepsilon = A\ V^{1.7} \qquad (1)$$

A is a constant

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Erosion rate is defined as the volume removed from the eroded material by unit weight of erosive particles.

Investigation of the effect of the shape of the particle on erosion of polyurethane indicated that erosiveness of particles increases with decrease in their roundness. The shape effect of the erosive particles S on erosion is defined as the ratio of the erosion rate produced by sub-rounded particles $\mathcal{E}_r$ to that produced by angular particles $\mathcal{E}_a$. The word sub-rounded is used to denote particles that are not truly spherical but have rounded corners.

$$S = \mathcal{E}_r / \mathcal{E}_a$$

It has been found that the erosion caused at small concentration of the erosive particles is larger than that caused at high concentration. The efficiency of the erosive particles η is defined as the ratio of the erosion rate of the material $\mathcal{E}$ produced by given weight of the erosive particles at a particular concentration to the erosion rate $\mathcal{E}_i$ produced by the same weight of the erosive particles at a very small concentration where each particle erodes ideally .

$$\eta = \mathcal{E} / \mathcal{E}_i$$

Investigation of erosion of different elastomers at different impingement angles indicates that elastomers are ductile materials in erosion sense and exhibit maximum erosion at an angle of attack about 20 degrees.

Finnie (5) proposed a theoritical model in which the erosion rate of ductile metal is proportional to the angle of impingement ,

$$\mathcal{E} = C\ f\ (\alpha) \qquad (2)$$

C is a constant ,
f (α) is a function of the angle α.

Little work has been done to study erosion of elastomers. The unsufficient work done necessitated a study of properties of material that effect erosion of elastomers. The present work is complementary to the author's work on erosion of elastomers. It is aimed here to connect mechanical properties, erosion parameters and erosion resistance of elastomers. Relationship between these variables can be used in selection of proper elastomers to be used for coating and protecting of materials having poor erosion resistance.

EXPERIMENTAL TECHNIQUE

Erosive air blast machine (4) was used to investigate solid particle erosion of elastomers. The erosive particles were quartz (99.08 percent purity), sub-rounded shape and size 400 - 500μm. Velocity of the erosive particles were determined with rotating mirrors instrument (4) and it was 62m/s. Investigations were carried out at an impingement angle of 10 degrees. Investigated materials were neoprene, viton, silicone rubber and polyurethane. Hounsfield testing machine was used to determine elongation and tensile strength of elastomers. Flat tensile specimens were prepared according to British Standard testing methods.

BEHAVIOUR OF ELASTOMERS ATTACKED WITH SOLID PARTICLES

To identify features of eroded elastomers, a specimen of an elastomeric material (polyurethane) attacked with solid particles was investigated in scanning electron microscope. Due to the large elstic recovery of polyurethane it was difficult to identify the erosion features of the eroded specimen . It was decided to replace the polyurethane specimen with a polymer having less elasticity than polyurethane. Polythane was selected and an eroded specimen of it was

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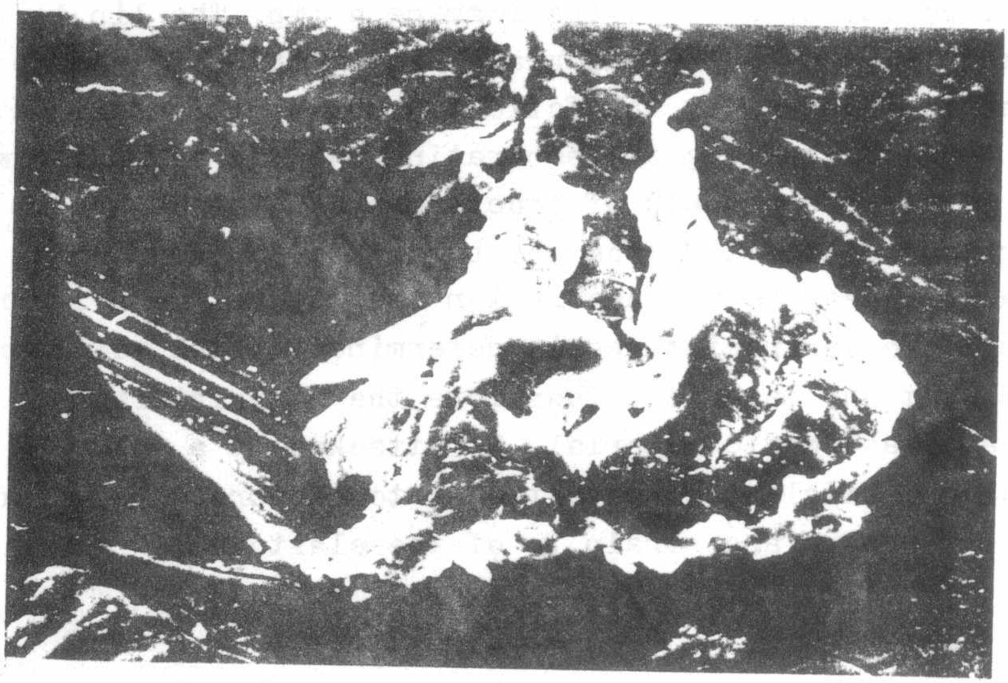

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Plate 1 Polythene eroded by 400 - 500μm sub-rounded quartz particles at a velocity of 62 m/s an impingement angle of 20 degrees, (X 50)

Plate 2 Is an enlargement of the area B in plate 1, (X 600). Taken from reference 4.

investigated. Plates 1 and 2 indicate that polythane is deformed, displaced in front and to the sides of the attacking particles. The plates show also that the material deformed by one particle is not always removed by the same particle.

Based on the erosion features of polythane shown in the plates, an erosion behaviour of elastomers is proposed. It is assumed that when a particle attacks a surface of an elastomeric material, the particle pushes up a surface section of the elastomer, compresses material in front and stretches that behind it. The deformed material either overcomes the push by its elasticity and then it returns to its former position, or it tears forming a lip. The lip is separated from the bulky material when it stressed and deformed to fracture by the following attacking particles. Work done for tearing and separating the lip is approximately equal to a product of fracture strength and strain . Separation of the lip from the bulk material represents the actual measure of the erosion resistance where in practic the erosion resistance is determined by the weight removed from the material. Therefore the material removed from an elastomeric material Q, attacked by a mass M of solid particles is proportional to reciprocal of fracture strength σ and strain Δ of the elastomer,

$$Q = BM/\sigma\Delta$$

where B is a constant

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EXPERIMENTAL VERIFICATION OF THE PROPOSED FORMULA

RESULTS AND DISCUSSION

The stresses and strains in an erosion process are complex and cannot be copied. So, the uniaxial fracture stress and strain were used to represent the work of deformation in the surface of the elastomer required to separate a lip from it. Volume removed from the investigated elastomers were determined at an angle of impingement of 10 degrees. The small angle was choosen to minimize embeding of particles in the surface which leads to confusion in measurements of weight loss from the specimen. Embeding of particles in the surface of the elastomeric specimens increases with increase of angle of impingement (4). Fig. 1 is a plotting of erosion rate versus the product of tensile fracture strength and strain . The imperical relationship obtained from Fig.1 between $\mathcal{E}$ and $\sigma\Delta$ is ,

$$\mathcal{E} = 4.8/\sigma\Delta \qquad (3)$$

σ in MPa
Δ in mm^3/g

Value of the constant B in the proposed formula is 4.8 MPa. mm^3/g

MEANING OF THE CONSTANT IN FORMULA (3)

In order to show that equation No.2 proposed by Finnie is applicable to elastomers, the experimental erosion rate of elastomers at different attacking angles obtained by the author (4) is compared with the model as shown in Fig. 2. To avoid discussion of terms rather than the impingement

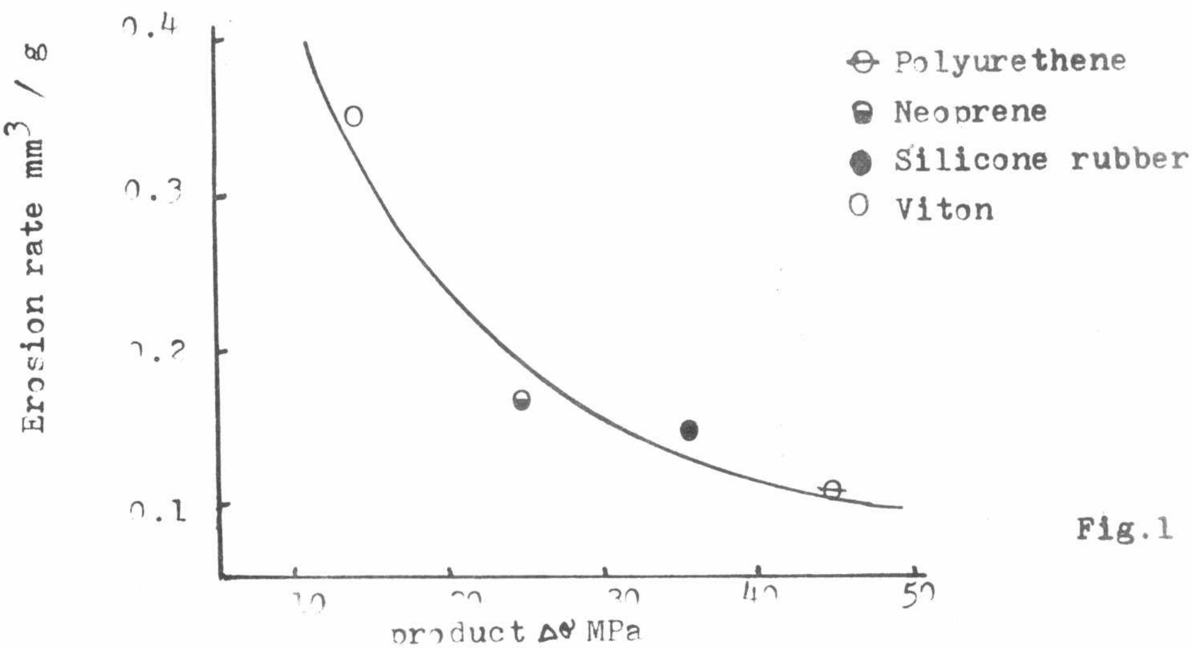

Fig.1

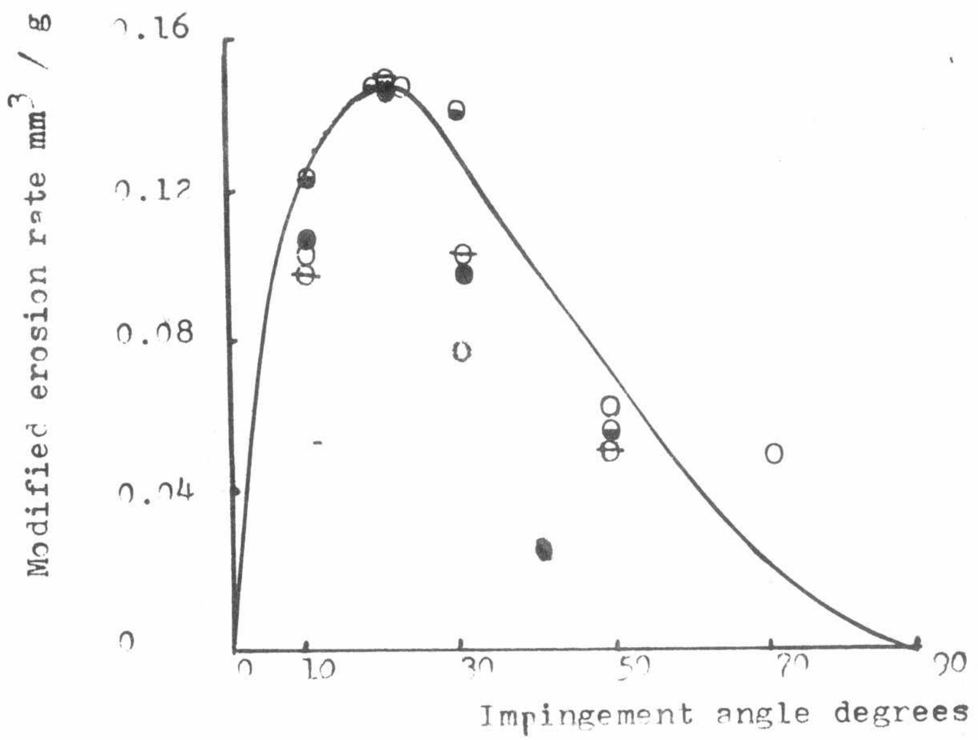

Fig.2

Fig. 1 erosion rate versus product σΔ of elastomers.

Fig. 2 comparison of experimental erosion rate of elastomers to the theoritical function f (α) . The points represent the experimental values of and the curve represents f (α).

angle, the experimental curves are normalized. That is the curves are scaled so that the maximum erosion rate of each elastomer is the same in all cases and equal to the value of f (α) at the theoritical maximum angle of erosion. Fig. 2 shows that the experimental curves compare well with the function f (α) . The deviation between the experiment and f (α) may be due to embeding of particles in the surface of the elastomers.

Plate 1 indicates that the material deformed with a particle is not always removed by the same particle . A factor N is proposed to represent the number of particles required to remove the material attacked by one particle.

Refering to equation No. 1, the exponent of the velocity of the erosive particles is 1.7. The reason for this low value of exponent is not clear. Theoritically, and for the purpose of evaluating the constant B in the proposed formula, value of the exponent is assumed equal 2. Combining equations 1 and 2 , it results ,

$$\varepsilon = GV^2 f(\alpha) \qquad (4)$$

G is a constant

Introducing the factors S, N and η in equation 4 and comparing it with equation 3, it results that dimension of G is a dimension of stress. Therefore G represents a mechanical property of the material, in other words it represents $1/\sigma\Delta$. Therefore,

$$\varepsilon = \eta SNV^2 f(\alpha) / \sigma\Delta \qquad (5)$$

Comparing equation 5 and 3 it results,

$$4.8 = \eta SNV^2 f(\alpha)$$

Mean values of S and η were determined in previous work executed under the present experimental conditions and are equal to 0.34 and 0.5 respectively . Value of N was determined by introducing values of f (α) , S and η (at nominal impingement angle of 10 degrees and velocity of erosive particles of 62 m/s) . The calculated value of η is equal 0.062 .

Valueof N indicates that 100 particles are required to remove the lips formed by 6 particles. Refering to plate 1 value of N was calculated equal 0.1 . The difference between the two values obtained is due to the different materials used . However, the obtained value of N with the other values of η, S, N, V and f (α) clarify the meaning of the constant B in the proposed formula.

CONCLUSION

From a study of erosion of elastomers the following conclusions are derived.

1. Elastomers are ductile materials in erosion sense and obey the theoritical relationship between erosion rate and angle of impingement suggested by Finnie. Erosive particles embed in elastomers and increasing their weight at impingement angles bigger than 40 degrees.
2. A model correlates erosion rate, parameters of the erosive particles and mechanical properties of elastomers is suggested and verified.
3. The constant in the suggested model is shown representing shape factor, efficiency, angle of impingement , velocity of the erosive particles, a factor represents number of particles required to remove the material deformed by one particle, true fracture strength and strain of the elastomer.

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4. The suggested model indicates that selection of elastomers with high erosion resistance to solid particles erosion is based on selection of elastomers having high true fracture stress and strain.

Finally, to protect materials which are susceptible to solid particles erosion, it is suggested to cover their surfaces with a thin layer of an elastomeric polymer.

For further work, it is suggested to study effect of the thickness of the coat on erosion resistance of the protected material .

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