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FLOW BEHAVIOR OF EPDM RUBBER OF DIFFERENT HARDNESS VALUES UNDER AXYSYMETRIC COMPRESSIVE LOAD IN DRY WORKING CONDITION

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Abstract: *Rubber is very useful and suitable material for a wide varieties of engineering and other applications. It possesses large elasticity compared to metals, has greater damping capability, high internal friction and can accumulate energy greater than that of steel or other metals. During the deformation of rubber material, e.g., by compressive force, internal damping of the material leads to energy dissipation. This is the cause of hysteretic friction of rubber. Friction of rubber material is of great practical importance at the same time it has so many disadvantages too.*

Use of rubber as engineering material is not new. However in the recent time its application is gaining importance due to several reasons. One of such reasons is that recent researches on rubber material reveals its suitability for engineering application. Several researches are going on, though it is rather very difficult to predict the exact behavior of any viscoelastic material like rubber.

In the present work compression tests were carried out to determine the flow behavior of EPDM rubber of different hardness values. Flat MS platens were used to apply axysymetric compressive load on the specimen under dry working condition. The flow behavior like load –elongation curves, true stress – true strain curves and specific energy requirements were computed from the experimental data. Statical hysteresis and the loss factors were also obtained.

Experimental results revealed that the hardness values of EPDM rubber had significant effect on the flow behavior. The hardness, again, depends on the carbon black content. Thus it can be stated that the flow behavior can be governed by controlling the CB concentration in the EPDM rubber. The test may again be extended with different lubricants. The present work was conducted in the laboratory of Mechanical Engineering department utilizing the rubber samples obtained from National Engineering Rubber for the purpose.

Keywords**:** EPDM rubber, compression ,flow behavior, hysteresis, loss factor.

1.INTRODUCTION

Rubber is very useful and suitable material for a large and varied number of applications both engineering and others. It possesses large elasticity compared to metals, has good damping capability and can accumulate energy to a greater extent than that of steels. It has also got very high internal friction. During the deformation of rubber, particularly by compressive load , internal damping of rubber leads to energy dissipation. This is the cause of hysteretic friction of rubber. Friction of rubber as a material is of great practical importance in so far as the tires of automobiles, wiper blades, rubber seals, conveyor belts are concerned. However the increased friction in the die-work piece mating surfaces during rubber forming operations will lead to a phenomenon 'pancaking' or 'barreling' which is undesirable. This is particularly true during upsetting operations. Friction which leads to wear and abrasion is also undesirable. Rubber finds wide engineering and other applications with or without the use of some lubricant. Automobile tires ,rubber bushes, gasket, rubber spring insulated buildings, dock fenders, seals, bearings, sealants and sluices are some common examples of engineering applications. Some other areas are like water proof attires, bungee jump cords, high speed racing car tires and other sports accessories [1].

Rubber-metal springs are conveniently used in road and railway transport vehicles. Over metal springs they have the advantage like reduced weight, reduced cost, improved absorbing and damping capacity of shocks and overloads. In railway vehicles rubber-metal springs are used as primary and secondary suspensions, elastic supports of aggregates, buffers and draw gear applications [2].

Assembly and maintenance of rubber springs are comparatively simple. Rubber- metal contact is found in different other applications like vibration control, power transmission systems, seals and rubber pad forming processes[3].In rubber forming process one of the dies is made of rubber. This process has the advantage like low cost of tooling, ease of operation, reduced damage of the work material as well as has the capability to produce complex geometries [4].

It is thus clear that rubbers of different kind have wide industrial and other application potentials. The property requirements for rubber, particularly for engineering applications, are also varied and highly demanding. This necessitates the development of different grades of rubber and recent researches in different parts of the globe aim on the development of reinforcements with organophilic clay, carbon nanofibres, carbon nanotubes etc. Addition of white rice husk ash (WRHA), silica, carbon black in different quantities are also some examples in this regime of reinforcement to produce different vulcanizates [5,6].

Fundamental studies of the properties of rubber including tribological properties, the study of friction wear and lubrication, are not new. However the state of art knowledge in this field has many questions, many clarifications are also needed till date. Nowadays being fueled by the varied engineering application possibilities of rubber of different kinds a renewed interest is noticed in characterization including tribo-studies of different kinds of rubber [5]. Characterization of rubber, like any other metal, is also important to forecast the behavior during actual working of the same. It is not out of place to mention here that the properties of viscoelastic material like rubber are very complicated and there is hardly any model which can uniquely define such behavior. In tribological state tests friction and wear characteristics are of great importance. Friction behavior of rubber is also very complex. The viscoelastic characteristics greatly influence the friction of rubber [7].

Mechanical performance of different kinds of vulcanizates had been studied by many researchers. Thermal conductivity, stress-strain relationship, tensile stress, dynamic mechanical properties, elasticity, strength and so on are some few to be mentioned [1]. However, compression tests of EPDM rubber were hardly noticed.

Main objective of the present work is to study the flow behavior of EPDM rubber of different hardness values under compressive load and dry condition. This was done by evaluating the stress-strain relationship, specific energy calculation and finding out the loss factor.

2. THEORETICAL FRAMEWORK

Flow curve of any material can be established either by tension or compression test. Researches reveal that formability of material is lowest at tensile stress whether higher strains are developed during compression. Hence, compression is popular way to develop flow behavior, that is, flow stress – flow strain data, in metal forming applications [8].

During compression test a cylindrical or some times a rectangular specimen is squeezed by compressive load which is applied by some suitable device. The specimen is to be placed in between two parallel , flat platens to apply axysymetric load as shown in Figure 1.

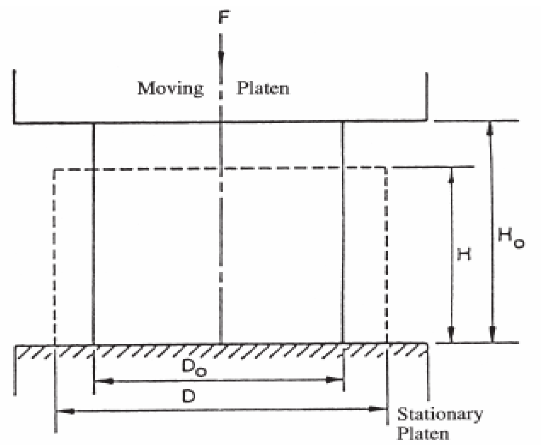

Figure 1. Homogenious compression of a solid cylindrical sample.

Throughout the test run the load and displacement, that is, the reduction in height values of the specimen are recorded. This data are utilized to find out various flow behavior of the material. Mathematically the stress and strain is expressed by the following relation:

$$Engineering\ stress\ \ s = \frac{P}{A_0}$$

and $$True\ stress\ \ \sigma = \frac{P}{A}$$

whereas , $$Engineering\ strain\ = \frac{h - h_0}{h_0}$$

and $$True\ strain\ = \ln\left(\frac{h}{h_o}\right)$$

True stress is the instantaneous load divided by the cross sectional area of the specimen at that instant, whereas, the engineering or conventional stress is the load divided by the original area of the specimen. Accordingly the true strain and engineering strain are also defined. In the above expressions 'h_o' is the original height and 'h' is the instantaneous height of the specimen[9].

Again we can define the strain rate as follows:

$$Engineering\ strain\ rate\ \ \dot{e} = -\frac{v}{h_o}$$

and $$True\ strain\ rate\ \ \dot{\epsilon} = -\frac{v}{h}$$

where, 'v' is the travelling speed of the die. The negative sign indicates the case of compression. We shall ignore the sign during our entire calculation for the simplicity of the purpose.

At the room temperature the flow behavior of majority of the metals is generally independent of strain rate. However, if the metal is worked at recrystallization temperature zone , that is, if hot working is conducted then the flow behavior depends on the strain rate. So during working at ordinary or room temperature any speed of the cross head of the machine is permissible for metals[8]. But the behavior of viscoelastic materials are completely different from those of metals. Mechanically the rubber materials are elastic at high strain rates whereas at low strain rate they are viscous.. Some researchers also demonstrated that the flow behavior of rubber is strain rate sensitive even at ordinary temperature.It is also not out of place to mention that several experimental observations of rubbers are not yet explained properly. As an example, coefficient of friction of rubber changes after a speed change, known as "conditioning" as per Schallamach[10].

Compression test is also associated with some problems. When the specimen is compressed in between two flat platens, lateral flow of metal in an outward direction leads to the development of shearing stresses at the die-work contact surfaces. This surface shear is directed towards the centre and opposes the outward radial flow of metal. The metal at the mid height of the specimen can flow in an outward direction freely. The combined effect of these two phenomenon leads to the development of barrel shaped part, known as barreling or pan caking. This may lead to problems unless controlled accordingly with the application of lubricants. Lubricants will reduce frictional force at the tool/die-work piece interfaces[4,9].

In axysymetric homogeneous upsetting operation we may apply the concept of constancy of volume. Thus if a specimen of initial diameter 'd_o' and height 'h_o' is compressed to a diameter 'd' and height 'h' respectively then from the concept of volume constancy we may write:

Initial volume (Q_1) = Final volume (Q_2)

or $$\frac{\pi d_0^2}{4} . h_o = \frac{\pi d^2}{4} . h$$

or $$A_o h_o = A h$$

or $$A = \frac{A_o h_o}{h}$$

where A is the instantaneous area.

In case of compression of a rubber specimen if the surfaces are oil or grease lubricated then minimal resistance is offered to the lateral slippage both at the top and bottom dies. On the contrary if the surfaces are firmly bonded to the platens then no lateral slippage will take place. Bonded versus unbonded surfaces thus lead to the generation of different flow curves. In ruber specimen shape factor also plays an important role[11].

Due to barreling it may not be possible to obtain data which are truely indicative of the process. Firstly, the cross-sectional area changes along its height and secondly, energy is dissipated due to friction which (that is the extra energy) is to be supplied through an increased compressive force.

As mentioned earlier, with proper lubrication barreling can be reduced to a greater extent.

In case of viscoelastic materials like rubber an interesting characteristic is observed during compression and subsequent relaxation of applied loads. It is observed that the loading path and the unloading path are not equal during the application of load and successive relaxation of the same. This effect is called hysteresis. Figure 2 shows a typical load-elongation curve for rubber, where the clockwise loop , formed in between loading and unloading path, indicates the hysteresis. Hysteresis is the energy dissipation capacity of rubber. By virtue of this characteristic rubber can absorb shock and damp vibration which enables rubber to be used beneficially in ruber-metal springs and other engineering applications where shock loading and vibration are prominent.

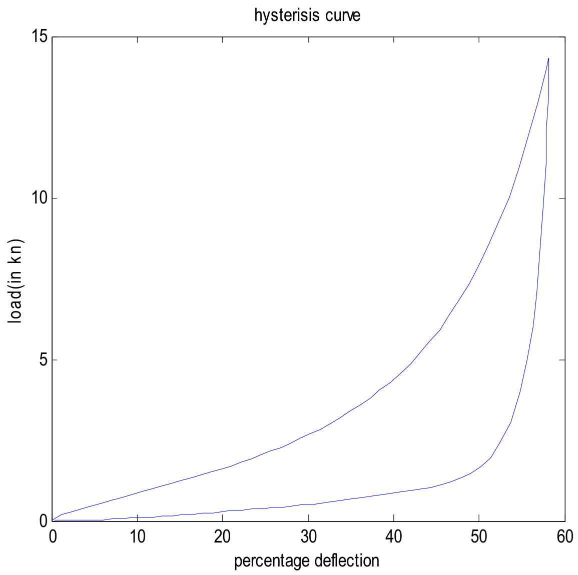

Figure 2. A typical hysteresis curve

When ruber specimen is compressed and then allowed to release subsequently it is observed that a fraction of energy which was put into the compressive specimen during loading is not recovered upon releae of load. The energy required to change the original shape of the specimen that is the strain energy is obtained from the area under the compression (loading) curve. Similarly energy released during relaxation (unloading) is also obtained from the area under the unloading curve. The difference gives the amount of hysteresis[2].

In case of compression of a viscoelastic material the exact nature of the curve is not kown as in case of purely plastic material the flow curve can be expressed in terms of well known power law equation $\sigma = K\varepsilon^n$. Hence the strain energy in case of rubber material is calculated using the Simpson's composite rule in this regard or by Trapizoidal rule[6]. The out line of such rule is mentioned below:

The interval of the curve [a, b] is subdivided into a number of small intervals 'n' ; 'n' being an even number. Simpson's rule is then applied to each subinterval and all such results are summed up. Thus,

$$\int_a^b f(x)dx \approx \frac{h}{3\left[f(x_0) + 2\sum_{j=1}^{\frac{n}{2}-1} f(x_{2j}) + 4\sum_{j=1}^{\frac{n}{2}}[f(x_{2j-1}) + f(x_n)]\right]}$$

Where, $x_j = a+jh$, for $j = 0,1,2,\ldots\ldots\ldots(n-1),n$

$$h = \frac{b-a}{n}$$

$x_o = a$, and $x_n = b$

Calculation of loss factor:

Loss factors may be calculated in several ways. To compare the loss properties of different materials a single method should be used. the Loss factor is obtained from the hysteresis loop by the following mathematical relation:

$$\eta = \frac{D}{2\pi U}$$

where, η = loss factor

D = energy dissipated per cycle

U = maximum strain energy per cycle

generally, $\eta < 1$: for material with lower loss

>1 : for material with high damping

All the calculations are done numerically using an indegeniously developed MATLAB code.

3. EXPERIMENTAL

3.1 EPDM rubber

Ethylene Propylene Diene Monomer rubber specimen were prepared in the laboratory of NEL(Rubber) using laboratory intermix and open mill in two steps. Theoretical proportions of the ingredients of EPDM rubber is as follows:

EPDM - 100 parts

ZnO - 5 parts

N-cyclohexyl-2-benzothiazole sulfonamide – 0.6 part

2 – mercapto benzothiazole – 0.6 part

Zn- dicyanatodiamine – 0.6 part

Zn- dibenzyl dithiocarbamate – 1.5 parts

Carbon black (CB) – in different portion depending on the hardness requirement e.g., 0,30,45,60 parts etc.

The actual recipe, however, is a trade secret and 'not disclosed grade'. The hardness differs with different proportion of CB contents.

3.2 Preparation of the test specimen

The basic ingredients, as mentioned, were first pre-mixed in a laboratory inter mix, type K4/2A-MK3, made by Alfred Herbert (net volume capacity 45 liters and fill factor approximately 0.6 to 0.75),for 6 minutes at a mixing temperature of 120^o -130^oC and at a ram pressure of 100 psi (7 kg/cm^2). Curatives were then added to the pre mixed materials on a two-roll laboratory mill (φ330 × φ150) at room temperature. The upper surfaces of both the roll is plated with hard chrome. A constant friction ratio of 1: 1.25 was maintained between the rolls. Total mixing time was approximately 10 minutes.

Processing characteristics including optimum cure time (t_{90}) and difference in torque ($\Delta M = M_h - M_l$) were then determined with the help of a rubber process analyser, Oscillating Disc Rheometre (Future Foundation, India made) being equipped with computer based data acquisition system and 'Rheosoft' software. M_h and M_l, high and low Mooney (torque) respectively, scorch time and optimum cure time (t_{90}) were noted. Approximately 10gm. of circular shaped sample were punched out from the uncured materials and placed between two rotating discs of the Rheometre at a constant temperature of 180^0C and at an arc of 3^0 for 6 minutes. The torque was monitored as a function of time. The time corresponding to the development of 90% of the maximum torque, that is, the optimum cure time (t_{90}) was measured from the corresponding rheographs.

The material, after qualifying the rheometric analysis, was entered in the molding press, which is a steam heated hydraulic press, made by Hydromech and Pneumatics pvt. Ltd., India. Molding of the samples were carried out in a die containing 9 cylindrical holes of Φ16.5 ±0.5 and h12.5 ±0.5 at a pressure of 3000psi and temperature 150^0C for 10 minutes as per IS: 3400 (part X)-1977. Silicon emulsion may have to be used in case the molten material sticks to the molding plates. The extra spew of materials were removed by scissor to give it the desired size.

3.3 Measurement of hardness

The hardness values of the specimen were measured according to IS:3400 (Part II) -1980 using a Shore (A) Durometer . TSE- Rubber Hardness Tester, SHR – Mark III –A ,sr.no.15718, made by Testing Machine, India, was used for the purpose. The machine was calibrated accordingly by Techno India. Indentations were made at several points on each specimen and the average value was then taken as a measure of hardness.

3.4 Measurement of the dimension of the specimens

Though the test specimens were produced using a dedicated mold for this purpose still it is very difficult to maintain exact dimensions of any viscoelastic material like rubber. Hence to cross check, the diameter and the height of each sample were measured using a Mitutoyo Digimatic Caliper (code no. 500-144, serial no. 0023360) equipped with SR44 battery. Measuring range of the instrument : 6 inch./ 150mm; resolution : 0.0005 inch/ 0.01mm; instrumental error : ± 0.02mm

3.5 Compression test

Test specimen was placed between two flat, axysymetric mild steel platens. Much care was taken to place the cylindrical specimen in between the platens and to place it perfectly at the centre. This is required to ensure an even force distribution on the face of the specimen. The required compressive load was provided by an Instron machine (model 8801; serial no. K 2342 with 'Dynacell' load cell, made in England. Maximum working pressure : 207 bar; dynamic load capacity : ± 100 KN). The machine is equipped with 8800 : Instron SAX V9.3 software based data acquisition system shown in Figure 3. Due to the want of a compression software , we utilized the fatigue cycle and only one cycle was utilized at a frequency of 0.005 Hz. The height of the cylindrical specimen was reduced by 65% for each sample. Each test was replicated twice to observe the repeatability of the process. The data of the compressive load followed by load relaxation were recorded and later utilized to plot the loading and unloading paths respectively. Following figure shows the compression test facility in Instron :

Figure 3. Instron (previous column) and associated computing system (above).

4. RESULTS AND DISCUSSIONS

Figures 4.1, 4.2 and 4.3 show the load-vs- % deflection , true stress-vs- % deflection and true stress-vs- true strain curves respectively of EPDM of different hardness under dry working condition. For all the EPDM with five different hardness experiments were replicated twice to establish the repeatability of the data and the test data thus generated reveal the representativeness of the experiments. Minor variations in test data were accepted considering the feasibility criterion of the experiments and the behavior of any viscoelastic material, discussed at length in the discussion section. Table 1 below indicates the different flow behavior values of EPDM rubber under dry working condition:

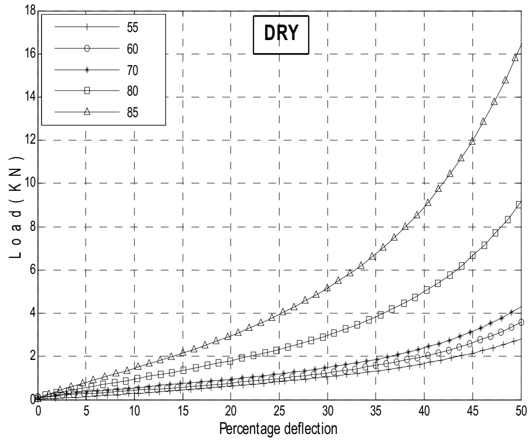

Figure 4.1. Load – % deflection curve

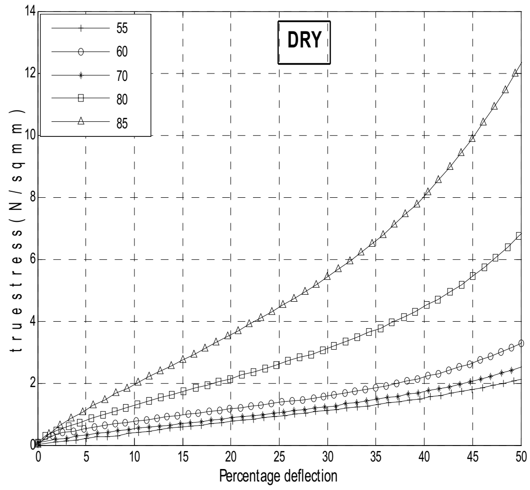

Figure 4.2. True stress- % deflection curve

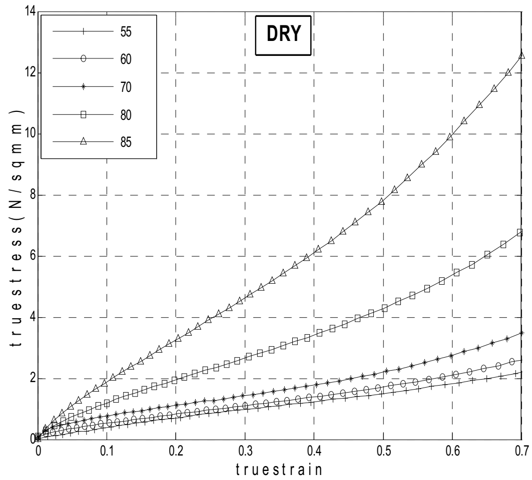

Figure 4.3. True stress-true strain curve

Table 1.

Hardness (Shore 'A')	Load (KN) at 50%	True stress (N/mm^2) at	True stress (N/mm^2)

	deflection	50% deflection	at true strain 0.7
55	2.71	2.08	2.16
60	3.35	2.41	2.53
70	4.05	3.15	3.47
80	9.03	5.95	6.75
85	16.57	10.00	12.53

The characteristic stress-strain curves for EPDM rubbers with different hardness are depicted in Figure 4.1. It is apparent from the curves that EPDM with hardness values of 55, 60 and 70 behave almost equally. However, reinforcing effect of 80 and 85 is significant. Reinforcing is generally done with different proportions of CB content (parts per hundred) . The observations are some how simlar with the test data of D.Felhos and J.Karger-Kocsis [5] where it reveals that EPDM 45 and EPDM 60 behave almost equally. In that test higher hardness values of EPDM were not considered. The present study also reveals that for low hardness values, e.g., upto 70, the nature of the stress-strain and stress-deflection curves are almost linear in nature. For hardness 80 and 85 linearity remains upto approximately 35% of deflection and 0.5 true strain respectively beyond which the curves are non-linear. For load – deflection ,however, the lower valued EPDM, upto 70, shows linearity upto 35 % and beyond this they are non-linear. For 80 and 85 non-linearity starts from approximately 25%.

In Figure 4.4 static hysteresis curves are shown.The corresponding values are tabulated in Table 2.

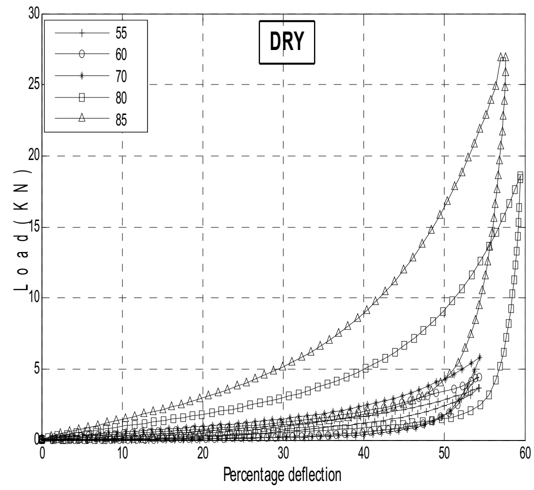

Figure 4.4. Static hysteresis curve

Table 2.

Shore 'A'	Accumulated Work	Released Work	Absorbed Work	Max. Strain Energy	% Hysteresis	Loss Factor
55	58.67	38.95	19.72	9.108	33.61	0.344
60	71.85	19.48	52.37	9.988	72.88	0.834
70	95.34	21.60	73.74	14.035	77.33	0.835
80	278.6	168.1	110.5	46.016	39.66	0.382
85	481.0	380.4	100.6	71.361	20.90	0.224

The hysteretic component results from internal friction of the rubber which is very high and at the same time elastic modulus of rubber is very low. Thus , as per Grosch studies, friction of rubber is directly related to the internal friction and a bulk property. Though this conclusion is not unique, as the behavior of any viscoelastic material, unlike most other solids, is very complex. Such internal friction results in the energy dissipation. Thus hysteretic friction of rubber is caused by internal energy dissipation during the course of deformation. This leads to the property of damping which is very useful in various engineering application like rubber-metal springs in railway and other vehicles, automobile tires, vibration damper and many more.

There are various ways of finding out loss factor and they are not necessarily compatable. Thus any one method should be used as a comparator of the loss properties of materials. In the present work loss factor was calculated on the basis of the generated hysteresis loop. Value of the loss factor is generally below 1 for low loss and may be higher than 1 for very high damping.

Here, EPDM with lower shore hardness tends to have a higher loss factor than those with higher shore values. Result of EPDM 55 differs , may be due to eroneous and/or uncontrollable test or due to inherent defect in the sample itself. Rest of the results are in close agreement with the conclusion driven by Martinelli B.A.E.[7] based on his experimental results. The nature of the experimental hysteresis curves are in perfect theoretical shape, i.e.,the well known banana curve of hysteresis.

Difficulty arises in providing the same average contact pressure on the specimen surface. The actual contact stresses , thus, will differ from specimen to specimen. It is also very difficult to place the specimen between the flat platens in a manner which will assure perfect alignment of the axis of the specimen with that of the platens. Alignment of the two axes is an essential minimum for axysymetric compression. During the experiments much care was taken to maintain all these.

Generally it is also very difficult to deform the specimen maintaining homogenity during compression testing. This is due to the friction between the specimen surface and the platens. Layer of material , adjacent to the platens, will be prevented from sliding radially outwards; whereas the remaining material is forced to move radially outwards by the dead metal zone as the compression proceeds[4,8,9]. This gives rise to barreling or pan caking. As a result of such barreling fresh surface area which was initially on the cylindrical surface of the specimen will come in contact to the advancing platen surfaces. Hence lubrication of all the surfaces of the specimen is very much essential to reduce friction and ultimately barreling. In the present study, however, only dry condition was considered. It is planned to extend the study in very near future with different lubricants to address the issue.

The Instron machine which was utilized to conduct the experiments was a displacement controlled machine where the cross head, containing the specimen can move with a prefixed constant speed. Though in case of cold forming operation of metals strain rate sensitivity is not applicable. But for viscoelastic material like rubber strain rate is important at room temperature too. Therefore in the present experiments no conclusion is made regarding the strain rate sensitivity on the flow behavior of EPDM.

5. CONCLUSION

The stated experimental work was devoted to study the flow behavior of EPDM rubber of different hardness, which depends on the amount (parts per hundred) of CB. The test conditions were very difficult to be harmonized as it should be during real operationg conditions. However much care was taken to maintain the test conditions at par and based on the experimental data following conclusions were drawn:

- with increasing hardness of EPDM true stress values are increased and are non linear in nature.
- reinforcing effect of the CB content is less significant upto EPDM 70. Strong effect was noticed in case of EPDM 80 and 85 respectively.
- hysteresis, which gives rise very important property damping, was noticed for each specimen. At the test condition %- of hysteresis was highest for EPDM 70. All the EPDM showed low loss(loss factor being less than 1) and EPDM with lower hardness values exhibit higher loss factor.

The results , in general, are qualitatively in agreement with the literatures and related other works done by other researchers in this area.

Future work would be to study the effect of different lubricants as well as different working conditions on the characteristics of EPDM under compressive load and care will also be taken, in particular, to improve the accuracy of the test results.

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