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UNIAXIAL DEFORMATION CHARACTERISTICS OF NR/BR BLENDED RUBBER UNDER LARGE COMPRESSION STRAIN

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ABSTRACT

The compression deformation behavior of elastomeric materials under large strain is still far from being understood today. A substantial body of research work on rubber blocks compressed between rigid plates has been developed, although many of the problems remain unsolved. Compression and shear deformation behavior of vulcanizates of natural rubber blend with different filler have been evaluated experimentally in this investigation for their nonlinear characteristics. The maximum bulge radius obtained by this method has been checked for its consistency with the established analytical models and are in good agreement. A significant increase in contact area has been observed in the images under large compressive strains. The compression and shear deformation behavior of rubber blocks under higher strain which have been evaluated experimentally could further support the currently adopted approximate analytical methods.

Key words: Quantitative, Strain, Compression, Deformation.

INTRODUCTION

Rubber is an important engineering material, which finds applications in various fields, as its different characteristics are of interest to the designer. The vulcanized rubber products are generally considered as incompressible, isotropic and hyperelastic. There are cases where rubbers can undergo considerable volumetric deformation under large strains (Donatello & Giuseppe 2012). An elastic rubber block (or spring) under vertical loading is one typical application. It is commonly accepted, that while the bonded surfaces slightly influence the shear behavior of a layer, they can cause drastic changes in its compressive and bending behavior (Gent et al., 2009). Most of the earlier studies on this subject have been

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based on assumed displacement fields with assumed stress distributions, which usually lead to average solutions (Tsai 2006, Huiming et al., 2013). Even though many features of rubber blocks have been deduced by means of analytical treatment, which is although approximate appears to give reasonable predictions (Mott et al., 1996). These assumptions have somehow hindered the comprehensive study; in addition the effects of geometric and material properties on the layer behavior could not be investigated thoroughly.

Fig. 1: Principal deformation modes of the rubber block

The major application of rubber blocks includes compression loading. The principal deformation modes of rubber blocks are illustrated in Figure 1. Under the application of shear force the principal effect is simple shear deformation, the most linear of all the modes of deformation, and one which is usually used as the basis for engineering calculations (Gent 2009, Patenaude et al., 2005). Under tilting or the rotational mode, the rubber block is subjected to pure bending by the bending moment. When the rubber block is compressed, the deformation is considered to take place in two stages, via a simple homogeneous compression, and subsequent shearing deformation that restores points in the planes of the bonded surfaces to their original positions in these planes (Gent et al., 2009). Also, the apparent modulus in compression is greater than the actual modulus (Mengi et al, 2008).

Deformation testing

The experiments were conducted on the rubber blocks to evaluate their deformation characteristics under uniaxial compressive loads. Fig. 2 shows a complete experimental set up used in the investigation. The experimental setup with an imaging tool has been used for the compression and deformation analysis of rubber blocks (Sridharan & Sivaramakrishnan, 2014). Natural Rubber (NR)/Polybutadiene Rubber (BR) blends were compounded with N330 carbon black filler and other ingredients. Rubber compounds are generally composed of a base rubber, filler, e.g. Carbon Black (CB), and curing agents (Mostafa et al., 2009). The NR/BR blend with different proportions of carbon black was mixed in the two roll mill, and samples are molded in the hydraulic press. Five different proportionate of N330 Carbon black as such 0, 15, 30, 45 and 60 phr were mixed with NR/BR blend along with other ingredients, and cured as stated above, to study the effect of CB loading on the vulcanized rubber block samples under compressive loads.

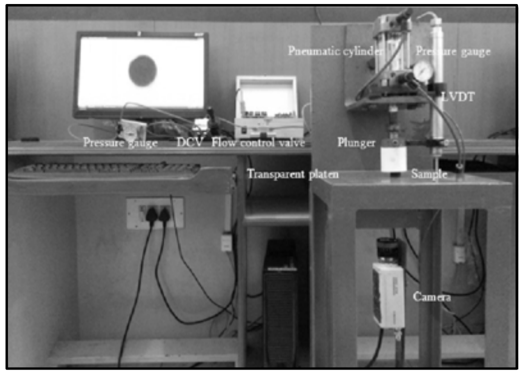

Fig. 2: Experimental setup

RESULTS AND DISCUSSION

All the tests were conducted by following ASTM D 575-91 (Dick 1995) standards and the results presented correspond to mechanical equilibrium. The deformation phenomenon was found to be common in the CB filled cylindrical vulcanizates, showing symmetrical bulging. Also, beyond 50% of linear deformation, the dimensional variation was found to be almost negligible, and the vulcanizate became highly stiff. From the investigation, it was inferred that the blocks bulge uniformly outwards for all the normal compressive forces and the bulging also progressively increased upon increasing the magnitude of the compressive force. The most significant finding of the imaging tool is to determine the maximum central bulge radius (R_{max}) for the corresponding linear strain. Fig. 3 presents the experimental R_{max} values as a function of linear Strain for the unfilled and CB filled sample having aspect ratio 0.8 and compared with the established Gent and Mott analytical models.

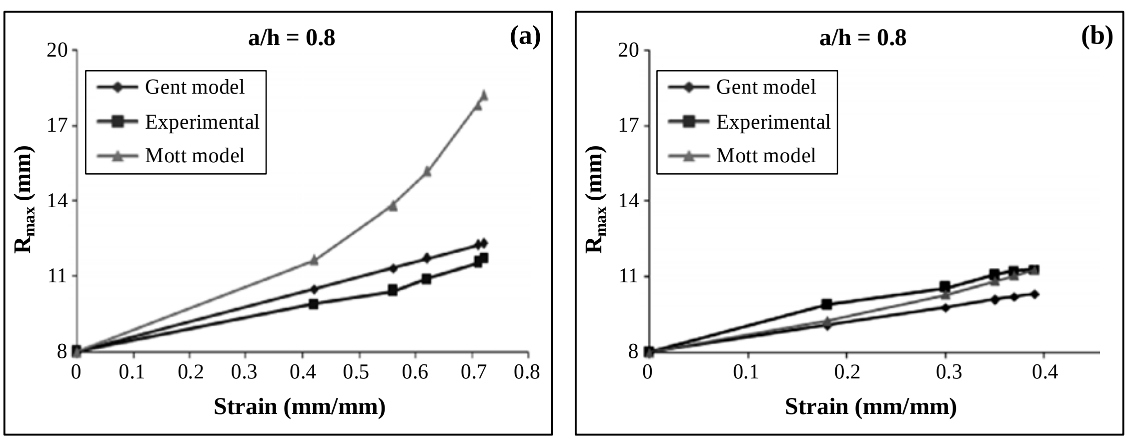

Fig. 3: R_{max} as a function of strain for the unfilled (a) & CB filled sample (b) with a/h = 0.8

When the compressive force was applied on the unfilled cylindrical blocks of different aspect ratios, considerable increase in contact area was observed. The increase in contact area was observed in all aspect ratio samples. This is due to the fact that the free surface of the sample comes into contact with the platens. As the compressive force is increased, more and more free surfaces come in contact with the platen and the deformation appears to be highly nonlinear. When the unfilled vulcanizates are compressed more load free surface comes into contact with the platen owing to their lower stiffness and on further loading the loaded area shows a fine increment. The deformation studies on CB filled samples showed comparatively a linear range of increasing bulge radius as they were stiffer than the unfilled samples. Carbon black filled and unfilled samples show similar trend in bulging but, the variations are observed in the strain level for the same magnitude of applied compressive force.

The axial deformation of the unfilled samples of different aspect ratios has been presented in this section. The samples were compressed uniaxially and the deformation height was obtained from the LVDT fixed in the compression fixture. Fig. 4 depicts the deformed height as a function of aspect ratio for the applied compressive force on the unfilled and CB filled samples. The samples under compressive load showed substantial variation in the deformed height as well as in the change in contact area. The samples exhibited an increase in the contact area on the platens and also a variation in maximum bulge radius in the mid-plane for all the compressive loads.

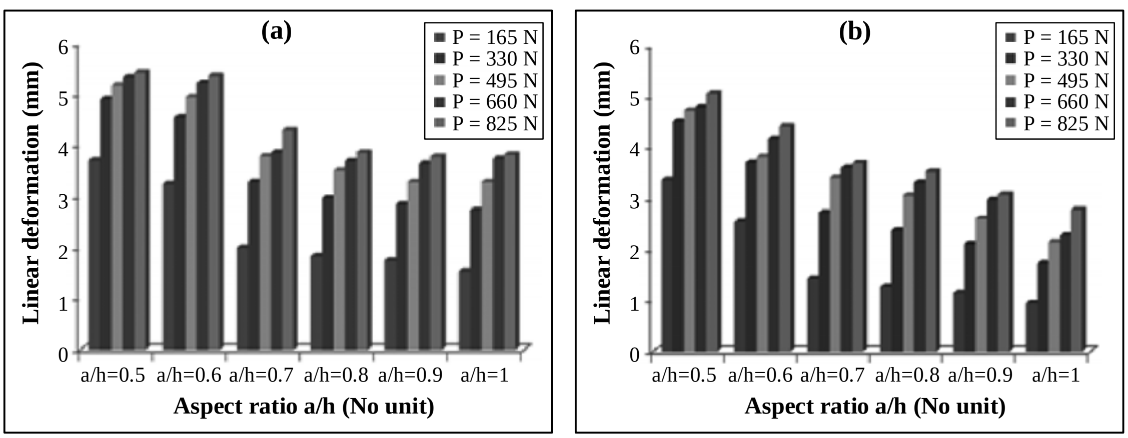

Fig. 4: Linear deformations as a function of a/h on unfilled (a) & CB filled sample (b)

The deformation phenomenon was similar in CB filled and unfilled samples but at higher strain, above 50 percent the smaller aspect ratio CB filled samples showed minor variation in deformed height as well as change in the bulge radius i.e. almost negligible even after appreciably increasing the compressive load. However, the unfilled samples continued to exhibit its response for linear and lateral dimensions variation towards the compressive loads applied on them.

CONCLUSION

In the present work, an attempt has been made to study the deformation behavior of uniaxially compressed rubber block, by using the imaging technique. Under uniaxial loading of the rubber vulcanizates, a substantial increase in the contact area was identified under large compressive strains. The R_{max} values obtained were checked for their consistency with the established models and found to be in good agreement. From the experiments conducted on the cylindrical blocks without CB filler it has been inferred that the normal stress have a maximum value at the center and fell down towards the edges while the shear stress rises from zero at the center to reach maximum at the edges. It is clear from the images obtained at higher strains that the stress distribution is non uniform in the non-bonded cylinders and the lateral profile appeared to be more flat than parabolic.

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