

Compression Force of a Form-In-Place (FIP) Conductive Elastomer EMI Shielding Gaskets: Theory, Measurement Techniques, and Application

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Abstract

The compression force of a FIP elastomer gasket during assembly and use is not a single number, but exhibits a dependence on the material, the method of measurement, and the conditions of use. FIP is a material which exhibits viscoelastic behavior and, as such, the gasket responds by deflection and creep to the dynamic forces incurred during assembly and the static forces present after assembly. Elements of part design also influence compression force. In practice, material hardness values have been used as to identify low compression force materials. The two properties, hardness and compression force, although correlated are not the same. Methods of measurement of compression force are described, with results presented for several types of FIP gasket. The preferred approach to evaluate the compression force of an FIP gasket is discussed.

Keywords: Form-in-place Gasketing, Electrically conductive Elastomer, Low compression force, time dependent strain.

1. Introduction

Form-in-Place (FIP) conductive gaskets are an automated system for dispensing elastomeric gaskets onto metal or plastic substrates for EMI shielding and environmental protection. This method of gasketing provides significant cost savings in the form of raw materials, labor and time. FIP gaskets are well suited for wireless handsets, PDAs, PC cards, telecom base stations, and many other compartmentalized electronic assemblies.

Typical FIP gaskets consist of a reactive, but not cross-linked, resin filled with conductive fillers. Cross-linking occurs after application by the user. Silicones are a commonly used elastomer for FIP gaskets, exhibiting a whole range of interesting and often unique properties. Silicones possess high thermal stability, an extremely low glass transition temperature, good weather resistance, and chemical resistance [1]. However, silicone resins are also well-known for their good dielectric properties. To reach high conductivity, over 50 volume

percent of conductive filler is loaded into the uncross-linked silicone resin, along with other reinforcing and functional fillers.

Silicone elastomers consist of cross-linked poly(dimethylsiloxane) polymer chains which are highly flexible. Under mechanical deformation, silicones dissipate hardly any energy as heat, which is consistent with very short relaxation times; deformation proves to be largely reversible [2]. In the case of filled silicone elastomers such as FIP compounds, the situation becomes more complex.

Silicone compounds containing reinforcing silica as a reinforcing filler exhibit pronounced pseudoplastic, thixotropic flow and have a tendency to undergo an increase in viscosity during storage [2]. Filled and formulated FIP systems can also exhibit strong interactions between conductive filler, silica and silicone, especially with the addition of chemical coupling-agents.

FIP is a material which exhibits viscoelastic behavior and, as such, the gasket responds by deflection and creep to the dynamic forces incurred during device

assembly and the static forces present after assembly. For FIP function a low gasket closure force is desirable, corresponding to the dynamic compression force. Moreover, to maintain a compression force from the gasket during operation is also important to preserve a good environmental seal and EMI shielding.

Compression force and deflection is therefore one of the critical properties which is studied by FIP manufacturers and their customers. However, there is sometimes a limited understanding of the compression force of FIP compounds, which may prevent customers from selecting the right FIP products and may mislead researchers' efforts to improve product properties. For example, hardness has been widely used as the property parameter to judge the low compression force materials. The two properties, hardness and compression force, although correlated, are not the same. In this study, the compression properties of FIP based on room-temperature vulcanizing (RTV) silicone have been extensively investigated with respect to theory, measurement, and application.

2. Theory

Figure 1 illustrates some basic properties of elastic, viscous, and viscoelastic materials with respect to stress (σ), strain (ϵ), and time (t). Viscoelasticity is

the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Basically, elastic materials respond nearly instantaneously when stretched and return to their original state quickly once the stress is removed as seen in Fig. 1 (a). Viscous materials respond gradually with time to applied stress, and retract slowly after the stress is removed, as seen in Fig. 1 (b). Viscoelastic materials have elements of both of these properties and, as such, exhibit time dependent strain. Viscoelasticity is due to a molecular rearrangement in the materials under stress and after removing stress. For FIP materials, macroscopic arrangement of the conductive filler cannot be neglected either; this will be discussed later.

Some phenomena in viscoelastic materials [3] are:

- (i) if the stress is held constant, the strain increases with time, called creep, Fig. 1 (c);
- (ii) if the strain is held constant, the stress decreases with time, called stress relaxation, Fig. 1 (d);
- (iii) the effective stiffness depends on the rate of application of the load, Fig. 1 (e), the strain rate $\dot{\epsilon}$; and
- (iv) the rebound of an object following an impact is less than 100%, i.e. a residual strain left, as seen in Fig. 1 (f).

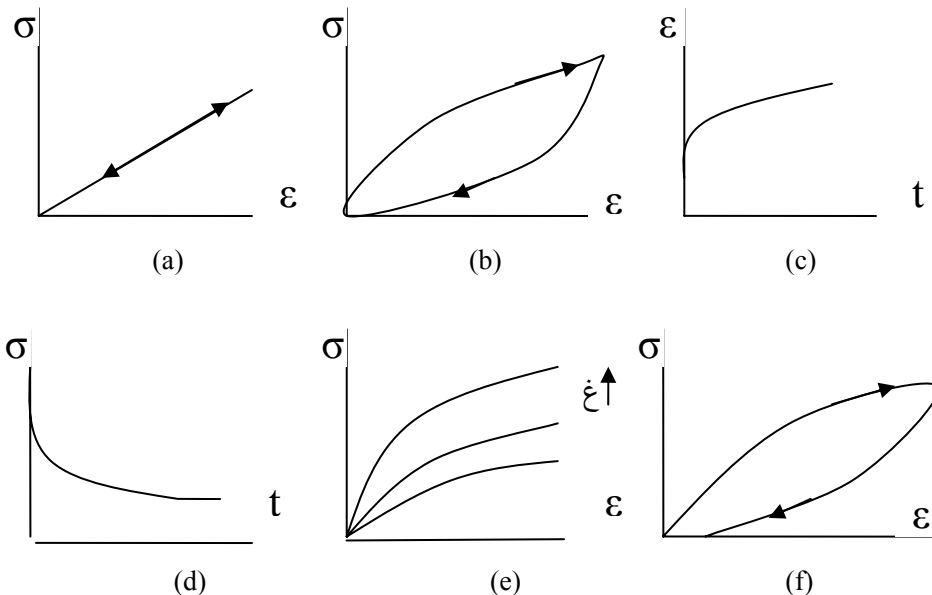
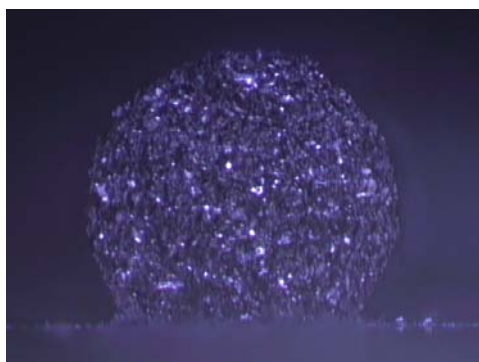


Figure 1. Basic stress-strain properties of viscous, elastic, and viscoelastic materials.

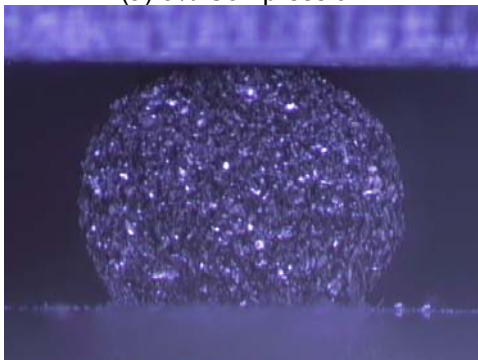
FIP gasket material exhibits viscoelastic behavior when compressed, and these effects must be taken into consideration to design gaskets effectively. As shown in Figure 1, there is a relationship between stress σ and strain ϵ . The ratio of σ vs. ϵ is modulus. Only at very low ϵ is there a linear relationship between stress σ and strain ϵ , called Young's modulus. Some silicone suppliers may also provide the modulus under a specific strain. Low modulus materials will require lower stress to get same level of strain. To develop low compression force materials, a low modulus silicone should be considered first. However, commercial silicone choices are limited. Additives which soften the polymer system will help decrease the modulus of the FIP compounds and, in some cases, coupling agents can modify the interaction between silicone and conductive filler and thus decrease the modulus of the formulated system.

It is interesting to monitor the structure change of FIP materials under dynamic compression *in situ*. It is also valuable to observe the structure change of FIP materials under static compression at different levels of compression. Figure 2 shows the morphology of

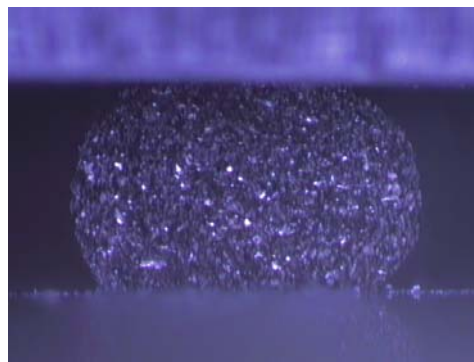
the transverse cross-section of a FIP bead under free standing, 12.5%, 25%, and 37.5% compression. It is apparent that the width of the FIP bead increases with the decrease of the bead height up on applying compressive force. Moreover, as seen from Figure 2, there is a large volume shrinkage during the compression. The higher the compression amount, the larger the volume shrinkage becomes. Since there is no significant change in the longitudinal direction, it is reasonable to calculate the volume shrinkage based on the cross-section area change only. Table 1 lists the size, area, and volume shrinkage ratio of the FIP bead under different amounts of compression. As listed in Table 1 for the investigated FIP bead, there is 25% of volume shrinkage of the bead under 25% compression. Such high shrinkage under compression indicates that the internal structure of the cured FIP gasket is actually porous though the surface is water impermeable. Time dependent strain effects of FIP materials result from not only the molecular rearrangement, but also macroscopic rearrangement of the filler particles as well as the collapse or reorganization of the voids in the materials.



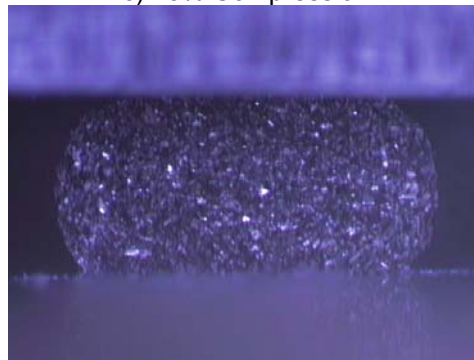
(a) 0% Compression



(b) 12.5% Compression



(c) 25% Compression



(d) 37.5% Compression

Figure 2. Morphology of the transverse cross-section of a D-shaped FIP bead in 12.5%, 25%, and 37.5% compression

Table 1. FIP bead size and area (transverse) change under different compression

Compression (%)	Bead width (mm)	Bead Height (mm)	Estimated area (mm ²)	Shrinkage (%)
0	1.37	1.16	1.59	0
12.5	1.42	1.01	1.30	18
25	1.52	0.87	1.19	25
37.5	1.65	0.75	1.13	29

The internal structure of FIP consists of 10 to 100 μm fillers, with some level of agglomeration, contained loosely in the continuous substrate of silicone. Such structure facilitates gasket formation by providing sag resistance after the bead is dispensed, but before cross-linking of the FIP paste. When the FIP gasket bead completes cure, it is robust with certain viscoelastic properties. Under compression, the contact between different fillers increases, which leads to good conductivity of the gasket. Figure 3 shows the relationship between the FIP volume resistivity and deflection. It shows that the FIP gasket will not have good conductivity below 10% compression, which means poor contact among conductive filler particles. When the

compression exceeds 10%, the conductivity increases slowly and gradually levels as filler contacts increase to provide more conductive pathways. Further compressing the bead (>40% deflection) will require dramatically increasing the compression force due to densely packed filler. Moreover, the filler and the silicone substrate may become fractured due to high shear forces. Figure 4 shows SEM images of the cross-section of an FIP bead under 10% and 25% compression. It is clearly seen that higher compression leads to dense packing and good contact of the filler particles. As estimated from Fig. 4, under 10% deflection, there are about 80-90 filler particles per mm^2 of FIP surface (a), increasing to about 100-110 particles per mm^2 under 25% deflection (b).

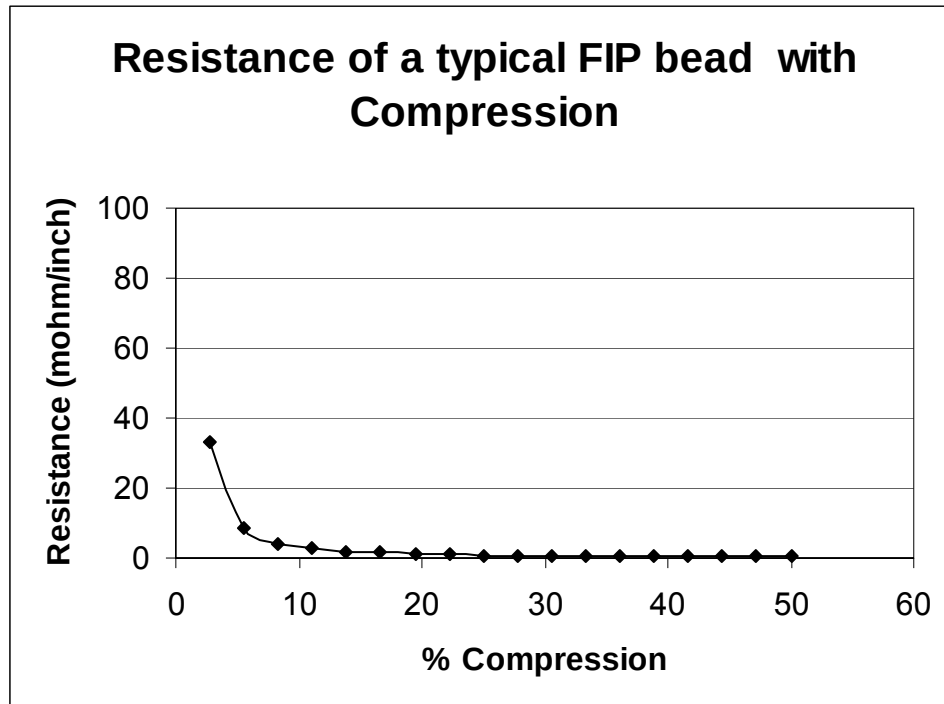
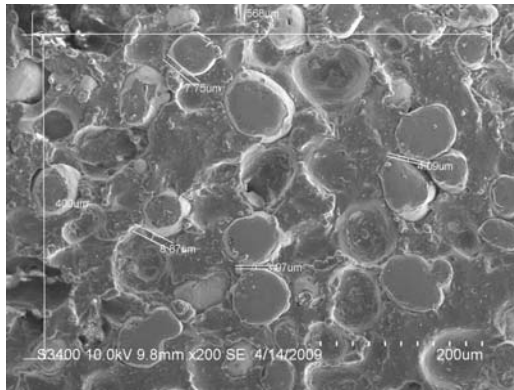
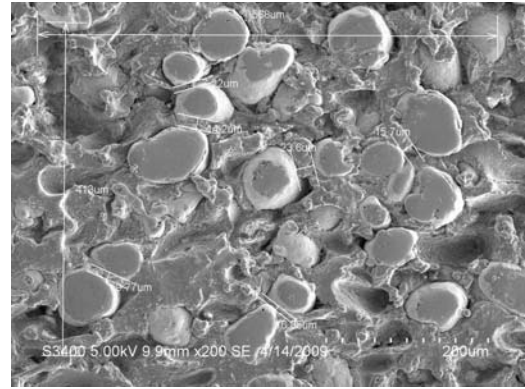


Figure 3 Resistance of a FIP bead under different deflection



(a) 10% compression



(b) 25% Compression

Figure 4. SEM images of the cross-section of one FIP bead under 10% and 25% compression

From observation and analysis, several ideas can be suggested to decrease the compression force to reach same level of compression in the application. First, good mechanical design to allow the FIP bead to be easily dispensed and room to relax under compression. Second, optimum bead shape so that a minimum of FIP deformation occurs. Third, optimum filler shape and particle size distribution so that the filler is packed in a loose but well contact pattern. Finally, decrease the filler loading to as lowest extent as possible.

It is common practice to use hardness as a standard to select low compression force materials. There is some correlation between hardness and compression stiffness; however, scientifically, they are much different. ASTM D575 describes to use disk sample to measure compression force vs. deflection to reflect the compression stiffness of the rubber [4]. Stiffness is an extensive property of the solid body dependent on the material *and* the shape and boundary conditions. This also applies to FIP products; the compression force used to compress FIP beads really depends on materials, bead shape, size and boundary

conditions such as the size of groove in which the gasket may be applied.

On the other hand, hardness of the FIP material refers to its resistance to various kinds of shape changes when a force is applied. A common method for describing the hardness of polymer materials is by durometer hardness, for silicones especially by the Shore A scale. This test method is based on the penetration of a specific type of indenter under an applied force. The geometry of the indenter and the applied force influence the measurements [5]. But hardness itself is dependent on the small-scale shear modulus in any direction. It is an intensive property that does not depend on the system size or the amount of material in the system. Normally, harder FIP materials will require high compressive force to reach same level of deflection. But there is some exception even with similar bead shape, size and boundary condition as seen in Table 2, which lists the hardness and compression force of four non-conductive FIP beads (freestanding D-shape beads, beads size around 1.3 mm width x 1.1mm height).

Table 2. Properties of four non-conductive FIP beads
(Freestanding D-shape beads, beads size around 1.3 mm width x 1.1mm height).

Non-conductive FIP	Shore A	Compressive force (N/cm ²)			
		10% deflection	15% deflection	25% deflection	30% deflection
Sample A	35	8.91	17.69	43.53	122.28
Sample B	37	7.89	13.43	27.24	77.60
Sample C	18	4.57	7.68	15.00	41.13
Sample D	18	7.54	13.34	30.01	78.26

3. Measurement

Compressive force vs. deflection is an important property and a straightforward criteria for selection of FIP materials. Two parameters, force and deflection values, can be easily obtained by instrumented mechanical testing. Deflection is defined as the percentage of the height variation vs. original height of the bead.

However, sample preparation and test parameters will significantly affect the measured results. Two kinds FIP bead have been used for study, one is a ring, and the other is straight strip, both with a D-shape cross-section. The ring-shaped sample simulates closely a typical FIP application, and as used herein is 1 inch in diameter. The straight strip sample is, after cure, carefully removed from the substrate and cut into 1 inch pieces for testing. Figure 5 shows the two kinds of samples used for study.

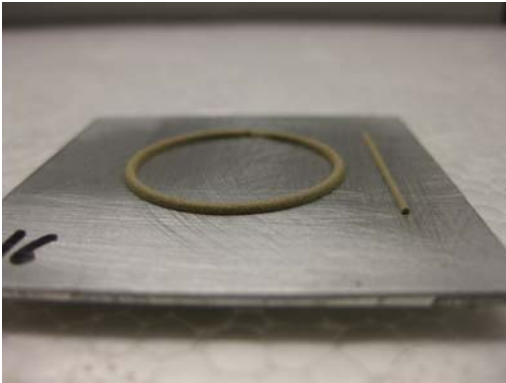


Figure 5 FIP samples for compression force vs. deflection test

As discussed in the preceding section, FIP beads are viscoelastic and material response is time and strain-rate ($\dot{\epsilon}$) dependent. Compression forces of FIP beads are typically

characterized by reporting a dynamic measurement and a static measurement.

Dynamic measurement represents a closing force, and is rate dependent. As shown in Figure 1 (e), high strain-rates during the test give high values of compressive force for same deflection. To simulate a real application, 6.35 mm/s (250 mil per second) has been used for dynamic measurements.

Static measurement represents equilibrium, and is time and temperature dependent. During the test for each deflection point, the FIP bead is held at each deflection for 30 seconds, and the equilibrium stress recorded.

Table 3 lists the compression force of one FIP sample under dynamic and static test. As shown in Table 3, for the same size of FIP bead, the compressive force to reach the same deflection during the static test is roughly one-third of the dynamic force measurement. The lower value under static measurement is because the viscoelastic materials will molecularly rearrange to minimize stress in response to strain. Moreover, macroscopic reorganization of filler particle will dramatically release the stress to keep same deflection.

The compression force from static measurements is valuable because it reflects the force to hold two pieces together with FIP gasket in the middle, which can instruct the design and arrangement of mechanical fasteners. Compression force from a dynamic test mimics the closing force to assembly the device with FIP gasket. Figure 6 shows the compression force vs. deflection plot of one FIP sample. Test samples are ordinarily tested in triplicate to create an average value for each sample. From this type of measurement, it is easily to read the compression force needed to achieve different levels of deflection.

Table 3. Compression force vs. deflection of a FIP sample under dynamic and static test conditions.

Load, N (lbf)				
0.72 mm bead height, 25.4 mm in length				
% Compression	10	20	40	50
Static	0.7 (0.4)	2.4 (1.4)	9.8 (5.6)	15.2 (8.7)
Dynamic	3.7 (2.1)	10.0 (5.7)	31.5 (18.0)	57.8 (33.0)

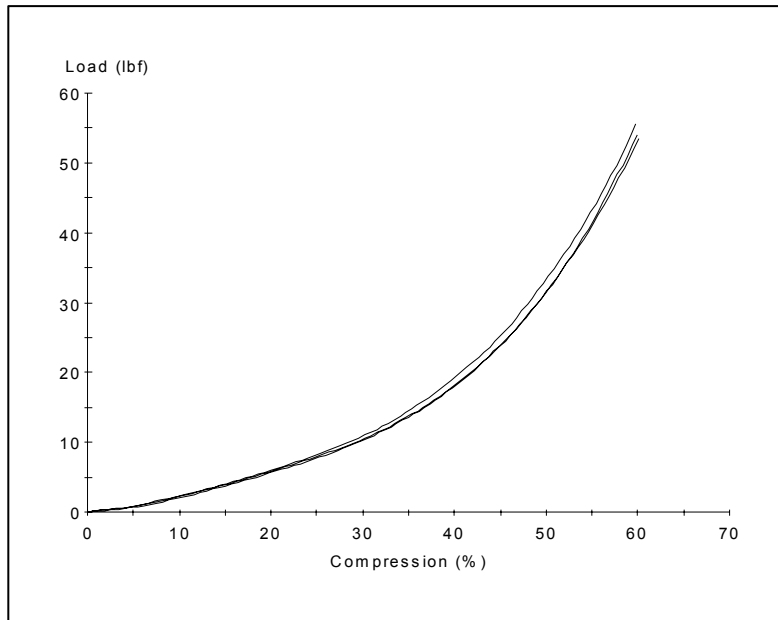


Figure 6. Compression force vs. deflection plot of one FIP sample.

4. Application

Several strategies have been described to create and use low compression force FIP materials. Some strategies are more applicable during FIP material development, while others are employed during application.

4.1 Mechanical Design

Good mechanical design of lands, grooves, surface planarity, and tolerances should be followed. These factors are beyond the scope of this paper, but should be taken into consideration during device design.

4.2 Bead Shape

Bead shape, as shown in Figure 7, also plays a role in compression forces. Figure 8 shows the compression force vs. deflection curves of the FIP beads with different kinds of cross-section, i.e., D-shape, double layer, and triangle shape. Double layer bead is achieved by dispensing two layers of D shape bead paste, after sagging and cure, it become a narrow D-shape, some times with a neck left in the middle. As shown in Figure 8, triangle-shaped beads need only about half compression force to reach same amount of deflection.

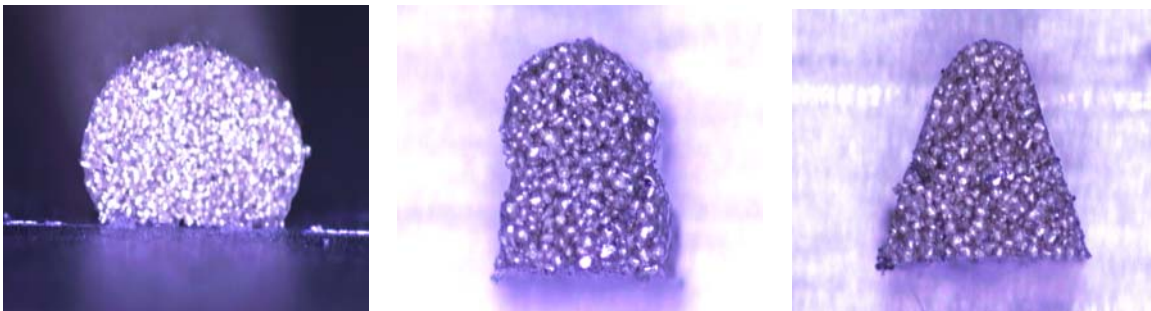


Figure 7. Different bead shape of the FIP materials, from left to right: D-shape, Double-Layer, and Triangular.

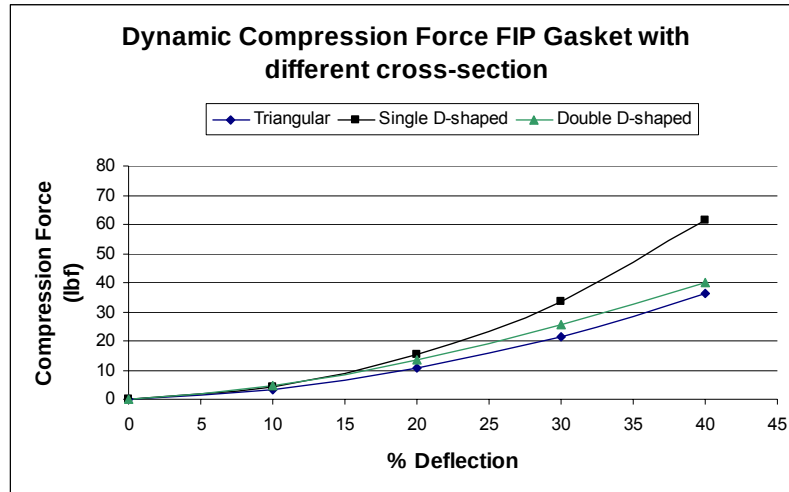


Figure 8 Dynamic compression force vs. deflection of FIP beads with different transverse cross-sections but comparable height.

4.3 Material Choices

Selection of a soft silicone base polymer is of course the starting point. As stated earlier, functional additives which have a cumulative effect on material properties can be incorporated. Selection of materials is within the scope of the formulator.

Different conductive fillers have also been studied. It is reasonable to say that particles can pack differently in response to compression, and some shapes may more readily move to release stress. Particle shape must also be considered with respect to other properties, such as volume resistivity or compression set.

Finally, decreasing the filler loading will of course will decrease the compression force, but it will be limited by the conductivity. According to Percolation theory, it needs certain level of filler loading to form a continuous filler connection to reach good conductivity [6].

5. Conclusions

FIP materials are viscoelastic materials in which high volume loadings of conductive fillers are incorporated into a continuous elastomer substrate. Under compression, there is a time dependent strain phenomenon, which results from not only molecular rearrangement of the elastomer but also macroscopic reorganization of the filler particles. The compression force of a FIP elastomer gasket during assembly and use exhibits a dependence on the material, the method of measurement, and the conditions of use. Accordingly,

strategies to develop low compression force materials have been proposed. Methods of measurement of compression force have also been described from the perspective of field application. The theory of compression force of the FIP materials has been successfully applied to develop desirable FIP products.

6. References

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