Super Soft, Very Low Compression Set, Material for Pressure Roller Application

Boris Avrushchenko, Wade Eichhorn, Dave Winters, 7-SIGMA, Inc, Minneapolis, MN

Abstract

Compression set of a material is critical in fusing system applications and is therefore desired to be as low as possible, less than 10%. Greater compression set introduces issues of loss of nip over time and elevated temperatures, adversely affecting the performance. With very soft materials, such as foam rubbers, compression set can be much greater than 20%. Tensile strength and elongation of materials are values that indicate the strength of a material under pressure in the fusing nip. Accordingly, a material with higher tensile strength and elongation is preferred. The hardness or softness of a pressure roller is dependent upon the base rubber material. Critical physical parameters of the material chosen are the hardness, compression set, elongation, tensile strength and dynamic responses under temperature and pressure.

This paper describes the evaluation of a silicone, non foam, rubber material with a softness of 15 Asker C and a compression set 8% or less, as applied to differing material thickness for pressure roller applications. Physical and dynamic properties of the super soft silicone rubber are compared against other rubber materials used in pressure roller applications.

Introduction

The design of pressure rollers, [1,2] used in nip forming fusing systems employ a single polymer material on a core or multiple layer configurations. Often fluoropolymer sleeves are bonded to a material for enhanced toner release or wear resistance. When a roller is designed using multiple layers of different polymers, the total hardness, or composite hardness, is a measure of the deformation capability of the roller under pressure. Selection of base materials are chosen from silicone, or fluorocarbon elastomer polymers. Furthermore, foam structures may be utilized, often to achieve a lower composite hardness. The most common polymers are classified as a high consistence elastomer (HCR), a liquid injection material (LIM), a room temperature vulcanized elastomer (RTV), or a foam version of each that incorporates air pockets or voids.

To achieve a roller of very low hardness, physical properties of materials, such as compression set are often compromised, thus contributing to failure modes which affect the performance or life of the roller in a fusing system environment. Compression set of a material is critical and is desired to be as low as possible, less than 10%. This is one of the issues associated with foam materials, which can have compression set as high as 50%, but which are often a choice for low hardness pressure rollers. Tensile strength and elongation of materials are values that indicate the strength of a material under pressure in the fusing nip. Accordingly, a material with higher tensile strength and elongation is preferred.

Dynamic properties testing of materials, such as Dynamic Modulus Analysis (DMA) is a test which indicates the stability of a material to continuous deformation. In this study we employed DMA analysis in addition to Hardness, Compression, Tensile and Elongation to evaluate the physical properties of a “super soft” LIM silicone rubber for application in fusing systems requiring a very soft pressure roller.

Discussion

The 15 Asker C material is a LIM silicone with a the unique property of very low compression set at elevated temperatures of 350F, making it suitable for fuser and pressure roller applications. Table 1 lists the initial physical properties and aged physical properties. Physical property measurements were carried out on a Shimadzu Rubber Tensile tester (model AGS-H; Autograph) for the determination of Tensile Strength (TS), Elongation at Break (EB%). Compression set was measured according to ASTM D396-97. [3]

Table 1. Physical Properties of Soft Rubber

Hardness, Shore A	**4**
Hardness, Asker C	15
Tensile, psi	163
Elongation, %	440
Compression Set, % (22hrs@350°F)	**5.3**
Tear	20
Abrasion Index (500g load)	0.015
Extractable Substances, %	49
Volume Change in Silicone Oil,% @ 300°F	16
Aging Properties (72 hrs @ 300°F)	
Hardness, Shore A	5
Hardness, Asker C	18
Tensile, psi	142
Elongation, %	330

Compression set testing of a sample is accomplished by compressing a 25 mm height sample to 75% of that height and keeping it in compression for 24 hours at 350°F under protocol of ASTM D395 [3]. The material is then allowed to recover without any compression for 1 hour where upon the thickness is measured and compression set, in percent, is calculated. Table 2 compares the soft LIM rubber with two samples of sponge rubber material.

Table 2. Compression Set Compared

Material	24hrs@ 350°F
soft LIM rubber	5%
Matl. grade AD24	23%
Matl. grade AD33	29%

Dynamic Mechanical Analysis, DMA, was conducted on the 15 Asker C LIM silicone rubber and 3 other LIM silicone rubbers that are currently utilized in pressure roller applications. Dynamic Mechanical Analysis was carried out using a Visco Analyzer 2000 DMA150 in compression mode at 25°C and 150°C. Storage and Loss Modulus were tested for each material over a frequency sweep 10 to 100 radians per second. Storage (E') and Loss Modulus (E") were measured and the Tan Delta calculated. Figure 1 shows the Tan Delta of the super soft rubber compared against 3 other rubbers of different hardness. The tan delta (tan δ) of a material is defined at the ration of the loss modulus (E") and the storage modulus (E'), and is a measure of the damping ability of the material when subjected to a sinusoidal deformation. The lower the tan delta is at elevated temperatures, the more thermally stable the material is. Accordingly, materials with a lower tan delta are generally a better choice. At room temperature the "super soft" 17 Asker C rubber has a tan delta comparable to the other rubbers, but at operational temperature of 150° C, the tan delta is consistently lower than the other silicone rubber materials tested. Because of the physical make up of foam with air pockets and voids, DMA testing is not applicable and therefore not compared.

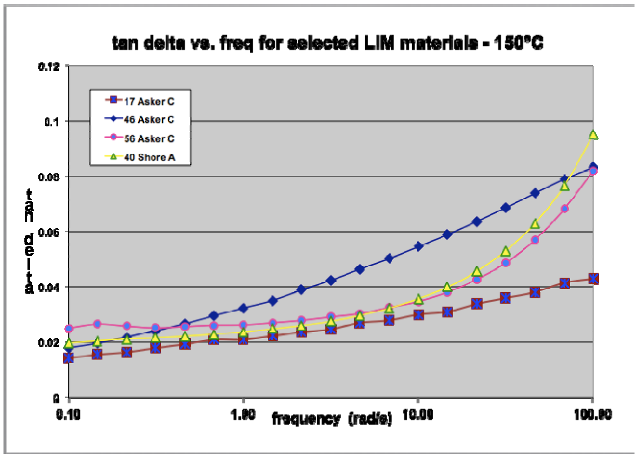

Figure 1. *DMA Tan delta vs frequency .*

A selection of materials were analyzed against a very soft LIM silicone rubber, with a softness of 15 Asker C. The materials selected were silicone rubbers and silicone foam rubber with hardness from 60 Shore A and below. Rollers were made with each of the materials and the composite hardness were compared ad well has the force needed to form a 10 mm wide nip. The pressure rollers made from each of the selected materials had the same final diameter but the wall thickness was varied ranging from 2.5 mm to 12.5 mm thickness. Each of the rollers contained an aluminum core and a base layer of rubber. In each of the wall thickness selections, rollers were made with top coatings of either a 40 micron thick PFA sleeve, or a 40 micron thick silicone release layer, or with no top coating at all. Each of the rollers were measured for composite hardness and the stress necessary to form a 10 mm NIP was evaluated. For this evaluation an aluminum indenter was made to use with a Tens meter to apply and to measure the force (lbf) applied to the roller. The length of the indenter was the same as the length of each roller, 230 mm. The width of the indenter was 10 mm. The indenter was mounted to the Shimadzu Rubber Tensile tester and impressed upon each roller to a depth of 1 mm. The stress (psi) applied to the rubber is calculated as the force (lbf) divided by the area of the indenter, 3.56 inches squared. Table 3 compares the composite hardness, and the force & stress needed to create a 10 mm NIP in. Table 3 is a sample of data collected from 35 rollers that were made and tested for this evaluation.

Table 3. Roller Hardness and NIP Formation Compared

Wall Thickness mm	**Sleeve Thickness**	**Composite Hardness**	Force for **10mm** NIP lbf	**Stress applied**
2.5	40	53	115	32
2.5	no sleeve	33	76	21
2.5	40u coat	32	75	21
5.5	40	43	52	14
5.5	no sleeve	22	34	9.5
5.5	40u coat	31	29	8.2
10	40	35	14	4
10	np sleeve	22	12	3.4
12.5	40	30	10.5	3
12.5	no sleeve	18	6	1.7

A foam roller with a wall thickness of 2.5 mm and a 40 micron PFA sleeve top coat has a composite hardness of 50 Asker C. The force applied to the foam roller was 44 lbf with a stress of 12 psi. While the solid silicone rubber rolls with the same 2.5 mm thickness and a 40u sleeve had similar composite hardness, the force and stress were more than double to achieve the 10 mm NIP. That is simply explained in that a solid is being compressed vs air. The advantage again for printer functionality is the compression set under load and temperature.

Figure 4 shows the force applied to the rubber rollers to form a 10 mm NIP as a function of material thickness, mm, on the roller as given in table 3.

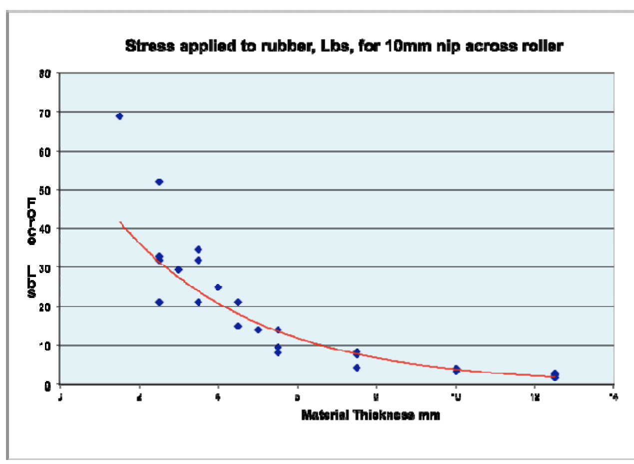

Figure2. *Plot of the stress applied to roller to form a 10 mm nip .*

Conclusion

The LIM silicone rubber described has a very low compression set at elevated temperatures while maintaining good physical and dynamic properties for applications in wide nip forming pressure roller. While not as “soft” as foam used in similar applications for a given thickness of material, the 15 Asker C silicone rubber has a significantly lower compression set as well as the physical properties of a real rubber. The dynamic properties have excellent response at 150° C, similar to those higher hardness rubbers currently used in pressure roller fusing applications. Use of this LIM silicone material for a fusing pressure roller applications [5] in color printers, where softness and large nip formation is desired, is a viable contender for further product evaluation.

References

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[3] ASTM D395 “Standard Test Methods for Rubber Property - Compression Set”.

[4] Kenneth Gillen, Modulus Mapping of Rubbers using Micro and Nano-Indentation Techniques., Rubber Chemistry and Technology, Volume 74, 2001

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Author Biography

Dr. Boris Avrushchenko is Senior Chemist for 7-SIGMA. Boris holds numerous patents in Russia and the U.S. on fluorocarbon rubbers and materials for the printing and areospace industries. Boris has worked for 7-SIGMA for 10 years.

Wade Eichhorn is New Technology Development manager and Product Manager for Fusing Systems and has worked for 7-SIGMA for 17 years.

Dave Winters is Analytical Chemist and has worked for 7-SIGMA for 6 years.