



Formulating FKM with varying levels of metal oxides

By Tejas Upasani
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Fluoroelastomers (FKM) were first developed and commercialized under the brand name Viton by E.I. DuPont De Nemours and Co. in the 1950s, primarily to address the challenging conditions experienced in the aerospace industry.^{1,2}

With advancements in chemistry and manufacturing techniques, FKMs saw increased acceptance in the automotive, industrial and consumer applications. ASTM D2000³ classifies FKM as HK material owing to its excellent heat resistance as determined by changes in specific properties at 250°C and maximum volume swell of 10 percent in IRM 903 oil.

TECHNICAL NOTEBOOK

Edited by John Dick

All FKM types are co-monomers with vinylidene fluoride (VDF) being the base monomer for most types. Homopolymer of VDF leads to highly crystalline polyvinylidene fluoride. To disrupt the crystallinity, monomers with bulky side groups such as hexafluoropropylene (HFP) are introduced. FKM polymers with VDF and HFP monomers result in type 1 (dipolymer) of the ASTM D1418⁴ classification.

To improve chemical resistance, the overall fluorine content is increased by the addition of tetrafluoroethylene (TFE). This results in type 2 (terpolymer) polymer. Those accustomed to specifying FKM materials would recognize type 1 and type 2 as Viton A and Viton B, respectively.

The outstanding properties of FKM elastomers are not realized until the polymer is crosslinked. Type 1 and 2 FKM are typically compounded with bisphenol AF (BpAF) as crosslinker and benzyl triphenyl phosphonium chloride (BTPPC) as the phase transfer catalyst (accelerator).

The FKM polymer has a fully

Executive summary

Curing of fluoroelastomers (FKM) can be accomplished commercially by three separate systems. The first curing system was developed using hexamethylene diamine. Although cured articles with diamines gave excellent heat and chemical resistance, processing was an issue.

The bisphenol AF cure system was developed in the 1970s as an improvement to diamines and has since been used as the primary curing method for a wide variety of FKMs. Some FKM types, though, cannot be cured with bisphenol and need to use a third type of cure system, namely the peroxide system. This is accomplished by incorporating a cure site monomer in the polymer backbone, which participates in the crosslinking mechanism.

In this article we explore varying levels of metal oxides within the bisphenol curing system and their effects on properties. The two most widely used metal oxides are magnesium oxide and calcium hydroxide. They can be used individually, but it is more common to use them in combination at different levels to achieve desired properties. The effects of these different levels on cure rate are important while formulating an FKM compound.

It is hoped that the information presented will aid in developing formulations that can achieve a balance between final cured properties and molding cycle times.

saturated backbone and therefore is not readily susceptible to attack by a nucleophile to form crosslinks. During crosslinking reaction, the polymer backbone undergoes multiple complex steps of dehydrofluorination in the presence of a base. These steps create a diene in the polymer backbone, which then results in crosslinks via addition of the diphenol.⁵

The most common bases used are magnesium oxide (MgO) and calcium hydroxide (Ca(OH)₂). It is important to recognize that the rate determining steps in FKM crosslinking are the dehydrofluorination steps, and these are not accomplished without the use of metal oxides. Schmiegel⁶ and Venkateswarlu⁷ have provided excellent insight into the crosslinking mechanism of BpAF cured FKM.

Fig. 1 shows the base, in this case calcium hydroxide, reacting with the accelerator (BTPPC) and curative (BpAF) to create an intermediate species (I), salt and water. Base catalyzed dehydrofluorination process occurs where hydrogen and fluorine atoms are removed from the backbone to create double bonds that rearrange themselves to provide a structure as shown in **Fig. 2**.

It is believed that formation of double bonds and attack of the

unsaturated backbone occurs during the induction period. Increase in torque on the cure curve occurs when both functionalities of the (OARO) are attached to polymer chains. Throughout the induction and crosslinking process, large amounts of fluoride ions are generated. These ions result in formation of HF acid, which is neutralized by the metal oxides to form metal fluorides and water. Thus, the metal oxides play a dual role of initiating the salt species as well as neutralizing the acid.

Fig. 3 shows a crosslinked polymer. BpAF level in a formulation decides the crosslink density, whereas the accelerator, BTPPC, decides the rate of the crosslinking process. Since the metal oxides are important to generate the intermediate species, their levels affect both the rate and density of crosslinks.

Experimental

All formulations in this study contain Viton AL-600 as the base polymer. A total of 30 phr of carbon black N990 and 2.5 phr of Viton Curative 50 (BpAF-BTTPC+ salt) were added to the base polymer to make a masterbatch (MB). This was then divided into 15 equal parts and the metal oxides were added on the mill at

amounts as shown in **Table 1 (A)**. **Table 1 (B)** shows all the tests that were performed on each one of the 15 batches.

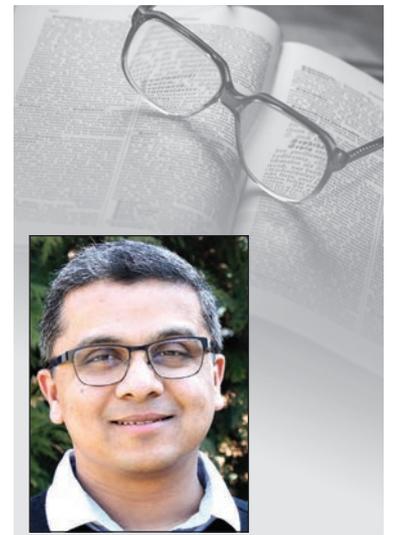
Results and discussion

Mooney viscosity

Mooney viscosity for all formulations is shown in **Fig. 4**. Each line indicates increasing Ca(OH)₂ levels at constant MgO. A neat linear relationship is observed for each one of the sets. With increasing total metal oxide content, the Mooney viscosity also increases.

Slopes from these linear relationships are plotted in **Fig. 5**. The higher slopes of 3.06 and 2.61 indicate that the viscosities tend to increase more rapidly when either of the metal oxides is present individually. In all cases, when Ca(OH)₂ levels are maintained constant and MgO levels are increased (**Fig. 5**, solid line), the slopes have lower values than otherwise—an indication that Ca(OH)₂ has a more pronounced effect on increasing the compound viscosity than MgO.

Increase in viscosity as a result of metal oxide additions is related to the ionic interaction and polar end group/filler interactions within the matrix. It is important to note that the trends shown here are related to Viton AL-600 as a base polymer, which is part of Viton's IRP generation. Viton polymers have improved in performance over various generations. One of the ways this has



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After an internship with GE Global Research in Niskayuna, he worked for Freudenberg-NOK Sealing Technology and held various technical and management responsibilities. In 2014, Upasani joined DuPont's (now Denka Performance Elastomer) neoprene business before accepting his current role of technical service and development with Chemours Co. to support the Viton-brand product portfolio.

been accomplished is by reducing the polymer end groups.

Older generations of the Viton family had higher ionic end groups and would show greater interactions with metal oxides and therefore higher and more rapid increase in viscosity with an increase in metal oxide content. **Fig. 6** shows additive effect in Mooney viscosity for various polymer types. In this case, Viton A is the oldest generation polymer, whereas GAL 200S is from the most recent Advanced Polymer Architecture technology.

Addition of 30 phr MT adds about 20 Mooney points for all polymers, but metal oxides (6 phr of Ca(OH)₂, 3 phr of MgO) add an additional 10, 18 and 49 Mooney points for GAL 200S, GBL200 and A, respectively.

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Fig. 1: Reaction of BTPPC, BpAF with base.

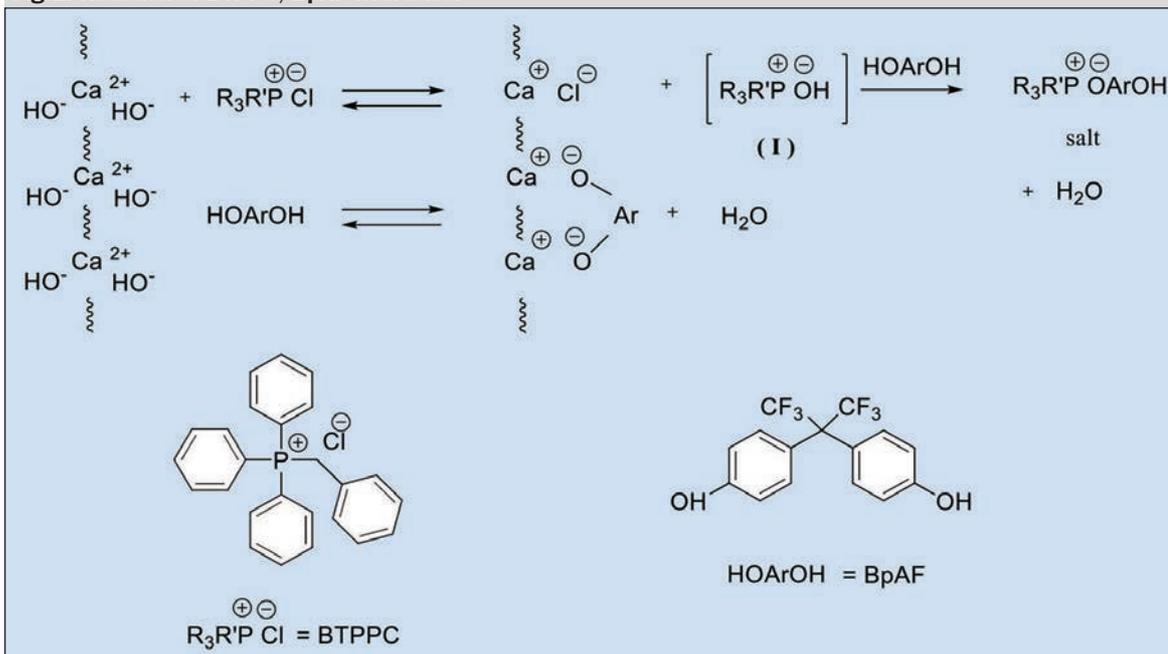


Fig. 2: FKM diene structure after dehydrofluorination.

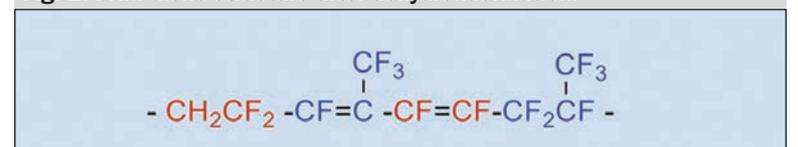
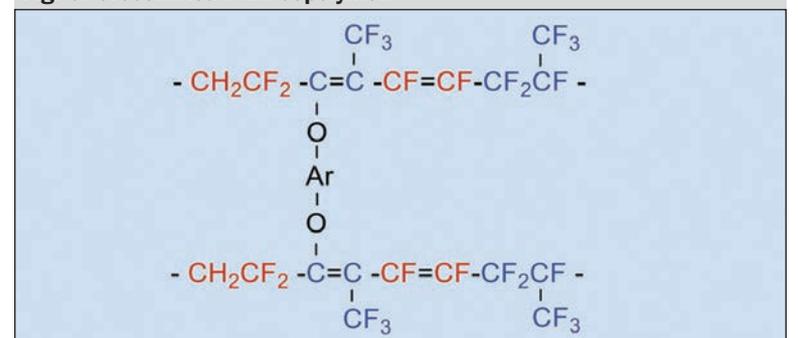


Fig. 3: Crosslinked FKM copolymer.





FKM

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Mooney scorch

Although MDR is used as a primary test for measuring the cure properties of a compound, Mooney scorch still provides decent information related to onset of cure. Fig. 7 shows the total millimoles of metal oxides (MO) present in the formulation and its almost linear effect on T1 value.

Fig. 8 provides the T1 values obtained for various formulations. At low total metal oxide, no T1 is recorded in 45 minutes. Six phr of Ca(OH)₂ with no MgO has a T1 of 38.7 minutes, whereas for 6 phr of MgO without Ca(OH)₂ yields 27.1 minutes, almost 10 minutes faster.

A similar trend is seen with 9 phr of each individual metal oxide. The T1 data suggests that when single metal oxide systems

are present, MgO activates the accelerator/curative more rapidly than Ca(OH)₂. This trend remains true even in mixed metal oxide systems.

Each molding process is unique. Combining the Mooney viscosity and scorch results should aid a formulator in deciding if the scorch results are ideal for achieving the cycle times while tolerating the corresponding rise in viscosity. While short molding cycle times are preferred, the results presented here show that achieving it with high levels of metal oxides may come at the cost of increased viscosity. This may not always be ideal, as higher viscosity may lend itself to flow-related defects.

Moving die rheometer (MDR)

MDR is the go-to cure meter for compound development, quality checks and providing guidelines for setting up a molding process. The torque values repre-

sented by MH provide an indication of the state of cure. Higher MH values, though, may not always indicate a stable, good quality crosslinked network. As shown in Fig. 9, magnesium oxide tends to have a more stabilizing effect on the final network, whereas Ca(OH)₂ shows reversion.

Induction time as referenced to the MDR curve is the time in the initial stages of the curing process after which the torque value starts to increase. In Fig. 9, the formulation containing only Ca(OH)₂ shows a longer induction time but a faster rate of cure than the one with MgO. Magnesium oxide for-

mulations providing shorter induction time and therefore lower Ts1 value are intriguing when trying to understand initial stages of the curing process.

Venkateswarlu⁷ indicated that the dehydrofluorination process and formation of monofunctional BpAF bond to the polymer backbone (Polymer - OAROH) occurs during the induction time. A shorter induction time with MgO suggests that it is a more effective cure activator than Ca(OH)₂. Table 2 gives various cure times collected for different formulations at 177°C.

Another way of understanding

the effect of MO on cure times would be with Pearson's correlation coefficients. The correlation coefficient (r) indicates a relationship between parameters but does not imply a causation.

Correlation between two parameters (x and y) can be given by the equation (a)⁸. The correlation values range between 0 to +1 and 0 to -1. Values close to +1 or -1 indicate a strong direct or inverse relationship respectively. Values closer to 0 indicate a poor relationship between x and y. While calculating the correlation coefficient, each one of the cure parameters (Ts1, Ts2, T5, T10, T50, T90, T95) was 'x', whereas the ingredient quantity, either MgO or Ca(OH)₂ was 'y'. Therefore, correlation coefficients for Ts1 and MgO, Ts1 and Ca(OH)₂, Ts2 and MgO, Ts2 and Ca(OH)₂, and so forth were calculated at different temperatures and are presented in Fig. 10.

Following are some of the observations deduced from Fig. 10.

- All correlation coefficients have a negative value indicating that an increase in metal oxide content decreases the cure values (i.e. faster curing) and vice versa.

- In Fig. 10A the 'r' values form an almost even crossover point between T10 and T50. For short cure times (Ts1), MgO formulation have a higher 'r' value (-0.73) than Ca(OH)₂, indicating a greater relationship. This value diminishes to -0.46 for T95. An almost exact opposite result is obtained for Ca(OH)₂ (-0.48 to -0.74). These values show the opposite relationship that MgO and Ca(OH)₂ have with lower and higher cure times.

- As temperature increases from 167°C to 197°C, the Ts1 'r' value for MgO decreases whereas Ca(OH)₂ increases, and they are almost equal at 197°C. This indicates that at higher temperatures, both metal oxides seem to have equal effect on the short cure times.

- At long cure times (>T90), Ca(OH)₂ formulations have greater relationship than MgO. This relationship starts to decrease as the temperature increases from 167°C to 197°C. It is important to know that injection molding typically has short cycle times and high temperatures. So the effect of adjusting Ca(OH)₂ at these temperatures may not have as great an effect on TC 90 as it would at low temperatures. This is inferred from the trend of 'r' values dropping from -0.74 to -0.50 for T95.

The correlation coefficient indicates relationship, and its intent in this study is to show a trend or provide directional analysis of changing MO levels on cure times at different temperatures. These coefficients were based on results from a single test. Additional efforts to perform a designed experiment (DOE) with replicates may improve the 'r' values to indicate much stronger or poorer relationships.

Physical properties

Almost always, formulation development is done with the intent of achieving final physical properties. Once these are achieved, adjustments are made to get the most economical molding cycle

Table 1: (A): Metal oxide levels.

Batch Number	Calcium Hydroxide (phr)	Magnesium Oxide (phr)
FKM 83	0	9
FKM 84	3	9
FKM 85	6	9
FKM 86	9	9
FKM 87	0	6
FKM 88	3	6
FKM 89	6	6
FKM 90	9	6
FKM 91	0	3
FKM 92	3	3
FKM 93	6	3
FKM 94	9	3
FKM 95	0	0
FKM 96	3	0
FKM 97	6	0
FKM 98	9	0

FKM 95 is shown here for informational purpose. Absence of metal oxides leads to no cure.

Table 1: (B): Compound tests.

Tests	Conditions
Mooney Viscosity	30' @ 121 °C, 1 min preheat, large rotor
Mooney Scorch	45' @ 135 °C, small rotor
MDR	20' @ multiple T, 0.5 deg arc
Slab Prep	10' @ 177 °C Post cure 16 hrs. @ 230 °C
Shore A Hardness	1 sec
Physical Tests	Die C
Compression Set	O-rings 168 hrs. @ 200 °C 70 hrs. @ 250 °C

Fig. 4: Mooney viscosity.

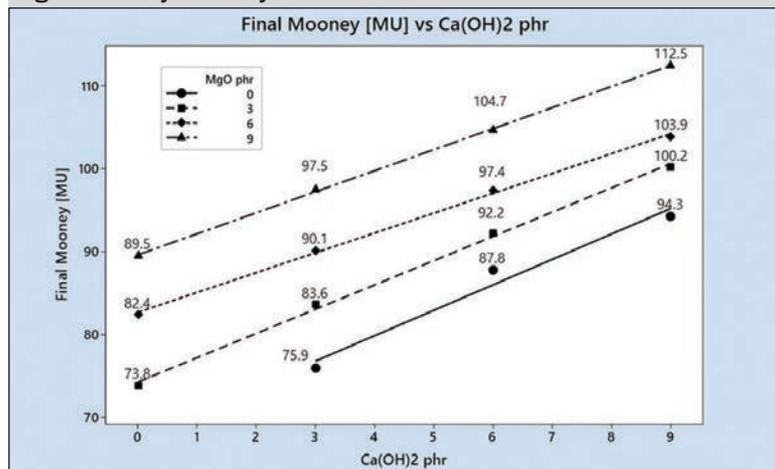


Fig. 5: Linear MV trend line slope as a function of MO levels.

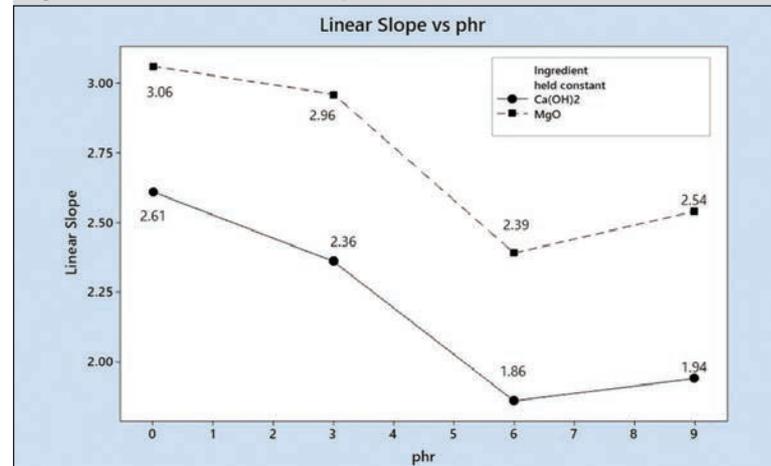


Fig. 6: Effect of end groups on Mooney viscosity.

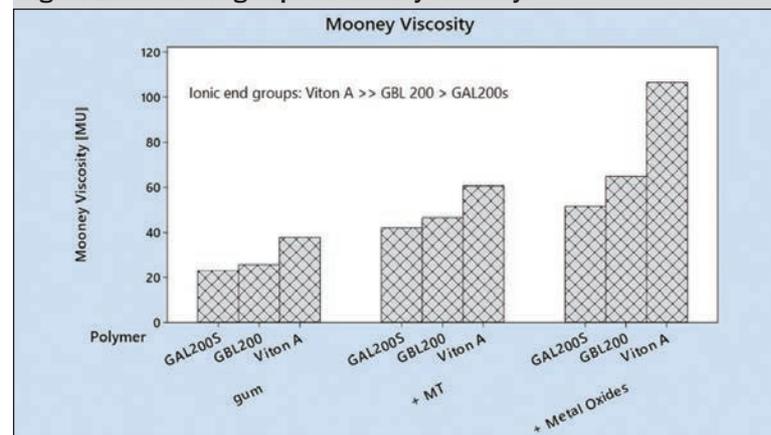


Fig. 7: Effect of total MO content on cure onset.

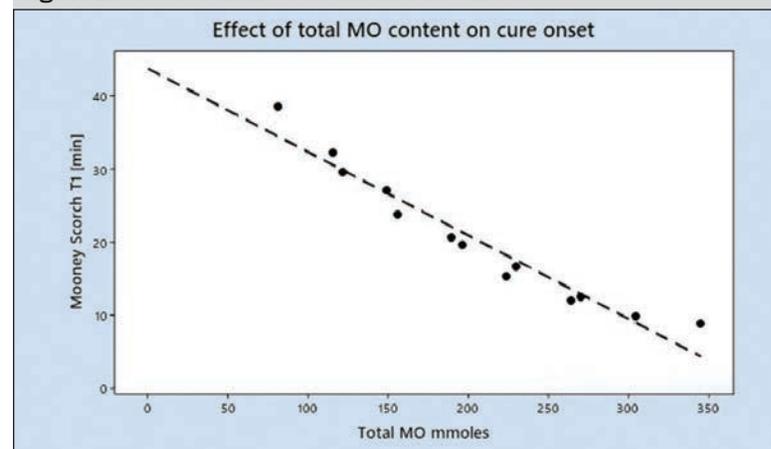
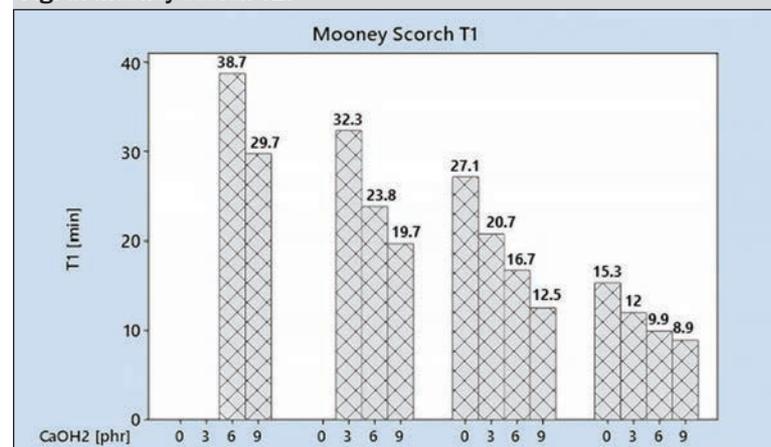


Fig. 8: Mooney scorch T1.



Technical

times. **Table 3** provides the post-cured (PC) physical properties obtained for all formulations.

One of the immediate effects of the two metal oxides can be seen on the tensile strength. High magnesium oxide formulations, especially with 9 phr (FKM 83-86) consistently show Tb >19 MPa. Similarly, formulations containing only MgO (FKM 83, 87, 91) have higher Tb than Ca(OH)₂ (FKM 96-98) formulations. This suggests a stable network with higher cross-

link density, an effect seen with the MH values for MDR results as well. Along with Tb, the hardness also shows better stability with MgO, whereas Ca(OH)₂ formulations (FKM 96-98) show much higher dependence of hardness on changes in Ca(OH)₂ levels.

The correlation coefficient (0.911) in **Table 4** shows a strong positive relationship between magnesium oxide and the tensile strength, whereas a poor inverse relationship with Ca(OH)₂ (-0.168).

Interestingly, a relatively high relationship exists between hardness and Ca(OH)₂ whereas almost none with MgO.

A positive value of 0.877 indicates that increasing Ca(OH)₂ results in increasing the hardness. In **Fig. 11**, the metal oxides show an opposing effect on the modulus values measured at various strains. At low strain (10, 25 percent), Ca(OH)₂ has a strong relationship, which diminishes at higher strain. The exact opposite effect is observed with MgO.

The hypothesis here is that in addition to forming a “base” network, Ca(OH)₂ might also lead to forming additional network structures that are of poor quality. This poorer network contributes to higher modulus values at lower strain, but breaks with increasing strain and, at higher strain, only the stable network can contribute to the modulus values. MgO shows higher modulus values and higher coefficient numbers, thereby suggesting that MgO might form a more robust base network than Ca(OH)₂.

Compression set

In sealing applications, compression set (CS) is one of the most important properties to predict the performance of an article. Upon being exposed to application conditions, the article should be able to maintain its original dimensions without resulting in a permanent deformation. Although the curative plays a dominant role in determining the compression set, choosing the right level of metal oxides could either help or harm the compression sets.

Table 5 provides CS results for all formulations at conditions as listed in the table. Additionally, the correlation coefficients also have been calculated and presented in the same table. A trend is seen where increasing the calcium hydroxide level tends to have a worsening effect on the CS values (FKM 83-86). The correlation coefficient values show an inverse relationship between MgO and CS. Although they are not strongly correlated—i.e. the values are not close to -1.0—a consistent negative value shows

that MgO assists in generating lower CS. Ca(OH)₂, on the other hand, has values close to 0.0, indicating a poor relationship with CS.

Results obtained for FKM 91 and FKM 96 seem to be related more to not having enough metal oxide in the formulation rather than whether MgO or Ca(OH)₂ is used. As was indicated previously, both MO actively participate in activating the cure process and these two formulations seem to be starved of MO, thereby not generating a stable network.

Conclusion

The use of metal oxides is essential in the curing process of bisphenol-cured fluoroelastomer. Of the various choices available, calcium hydroxide and magnesium oxide are the most commonly used metal oxides. These metal oxides perform a dual role of activating the cure system as well as acting as an acid acceptor to neutralize the hydrogen fluoride generated during the curing process.

Both metal oxides can play the dual role individually or together in a formulation. Evident from the results obtained in this study, magnesium oxide provides a short induction time and a slower rate of cure. Calcium hydroxide, on the other hand, gives a longer induction time but a much steeper cure rate. From a molding perspective, the latter would be ideal, and one would be inclined to use only calcium hy-

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Fig. 9: MDR plot at 177°C for select formulations.

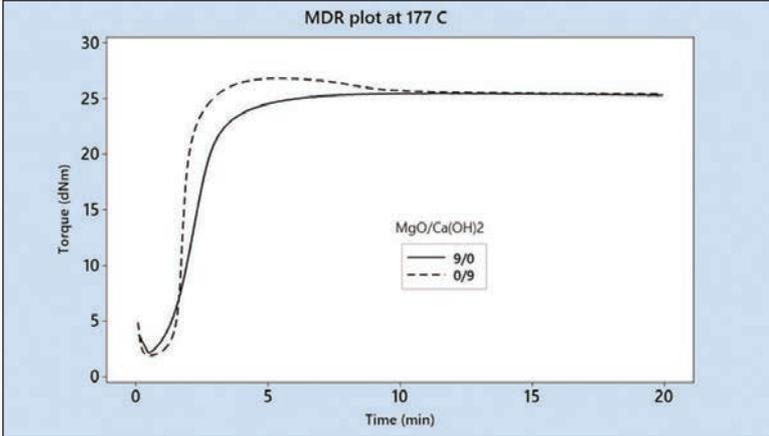


Table 2: MDR cure times at 177°C.

	Ca(OH) ₂ (phr)	MgO (phr)	Ts1 [min]	Ts2 [min]	T10 [min]	T50 [min]	T90 [min]	T95 [min]
FKM 83	0	9	0.94	1.18	1.25	2.22	3.68	4.68
FKM 84	3	9	0.78	0.92	0.94	1.36	2.12	2.67
FKM 85	6	9	0.67	0.77	0.78	1.04	1.55	1.95
FKM 86	9	9	0.63	0.71	0.73	0.94	1.4	1.75
FKM 87	0	6	1.33	1.71	1.89	2.95	4.7	5.94
FKM 88	3	6	1.06	1.27	1.36	1.84	2.81	3.49
FKM 89	6	6	0.90	1.05	1.09	1.41	2.13	2.63
FKM 90	9	6	0.76	0.85	0.89	1.10	1.59	1.95
FKM 91	0	3	2.06	2.74	2.80	5.66	11.71	14.46
FKM 92	3	3	1.38	1.69	1.81	2.45	3.78	4.70
FKM 93	6	3	1.09	1.28	1.36	1.72	2.59	3.19
FKM 94	9	3	0.96	1.11	1.16	1.43	2.12	2.59
FKM 95	0	0	-	-	-	-	-	-
FKM 96	3	0	2.04	2.51	2.47	3.76	5.59	6.71
FKM 97	6	0	1.50	1.77	1.84	2.34	3.59	4.35
FKM 98	9	0	1.23	1.43	1.49	1.80	2.68	3.21

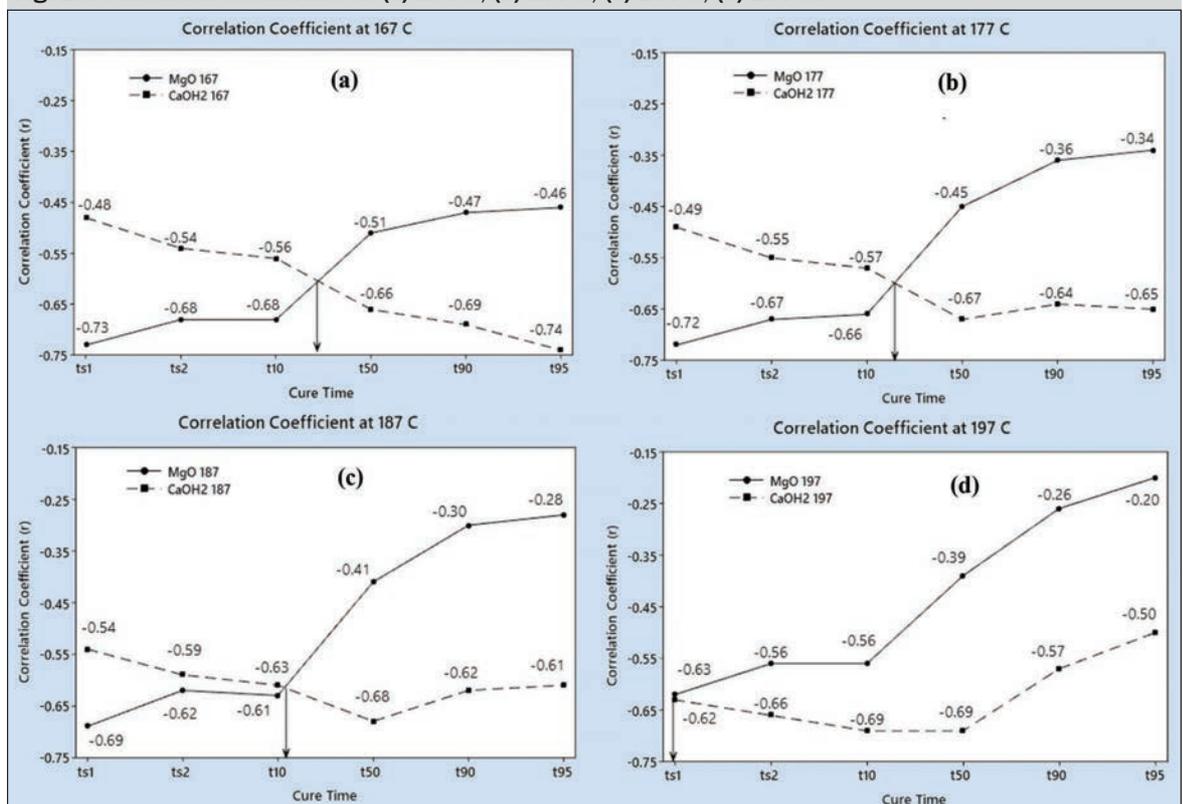
Table 3: Post-cured physical properties.

Form No. MgO/ Ca(OH) ₂ phr	Tb [MPa]	Eb [%]	M 10 [MPa]	M 25 [MPa]	M 50 [MPa]	M 100 [MPa]	M 200 [MPa]	Hardness [Shore A]
FKM 83 9/0	19.9	228	0.84	1.47	2.40	5.84	16.53	71.6
FKM 84 9/3	19.5	222	0.90	1.60	2.66	6.50	17.05	72.8
FKM 85 9/6	19.4	214	0.96	1.70	2.86	6.99	17.93	73.6
FKM 86 9/9	19.5	206	0.99	1.77	2.95	7.07	18.66	75.8
FKM 87 6/0	19.0	230	0.81	1.44	2.35	5.68	15.89	71.0
FKM 88 6/3	19.7	232	0.81	1.46	2.45	6.16	16.61	71.7
FKM 89 6/6	18.9	203	0.89	1.60	2.83	7.29	18.33	73.4
FKM 90 6/9	18.5	194	1.01	1.83	3.25	7.95	18.34	75.2
FKM 91 3/0	16.4	260	0.83	1.43	2.20	4.46	11.71	70.8
FKM 92 3/3	17.9	247	0.94	1.66	2.66	5.65	14.08	74.2
FKM 93 3/6	18.2	219	0.89	1.64	2.81	6.68	16.33	72.8
FKM 94 3/9	16.0	199	1.01	1.80	3.00	6.71	13.56	76.7
FKM 95 0/0	-	-	-	-	-	-	-	-
FKM 96 0/3	14.2	282	0.80	1.35	2.01	3.83	9.39	70.6
FKM 97 0/6	15.7	254	0.91	1.60	2.52	5.06	12.02	73.3
FKM 98 0/9	15.5	225	0.94	1.69	2.75	5.82	13.57	75.0

Table 4: Correlation coefficients for MO and PC physical properties.

Physical Property	Magnesium Oxide	Calcium Hydroxide
Tensile strength [MPa] PC	0.911	-0.168
Elongation at break [%] PC	-0.543	-0.601
Modulus at 10% [MPa] PC	0.116	0.834
Modulus at 25% [MPa] PC	0.151	0.853
Modulus at 50% [MPa] PC	0.295	0.806
Modulus at 100% [MPa] PC	0.589	0.587
Modulus at 200% [MPa] PC	0.829	0.244
Hardness [Shore A] PC	0.030	0.877

Fig. 10: Correlation coefficients at (a) 167°C, (b) 177°C, (c) 187°C, (d) 197°C.



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Tire makers in India battle new COVID-19 wave

By Don Detore
and Jim Johnson
Tire Business

and Rubber & Plastics News Staff

MUMBAI, India—While India is in the grip of a second wave of COVID-19, a sampling of tire makers in the country say operations continue to run smoothly.

Even with the dire pandemic statistics coming out of the world's second-most populated country, Balkrishna Industries Ltd. (BKT), Ceat Ltd., and Sun Tyre & Wheel Systems all report operations continue.

Sun-TWS reported operations at 100 percent capacity while BKT said operations are "running smoothly with an average of 95 percent capacity." Ceat, meanwhile, said it is following all safety protocols and running at "optimum capacity."

India reported 4,529 COVID-19 deaths on May 18, the highest daily total for any country reported to date. With more than 25 million cases and 283,000 deaths as of May 19, the country is struggling to provide health care to those in need.

Managing Director Rajiv Poddar of Mumbai-based BKT wrote a letter to industry stakeholders—issued to refute rumors that tire production had been impacted by COVID-19—in which he said production has not stopped at any plant site and no disruption is expected "in the near future."

"In case there is any disruption, you would hear it first from BKT as an official communication," Poddar wrote. "Although seemingly under control, the current situation is not very optimistic in terms of record number of cases reported or the related medical shortages."

"The situation on the ground is dire. Fortunately, our team in India and around the world, is safe



and constantly striving to keep the business at the normal levels."

Mumbai-based Ceat noted that the government of Maharashtra (the state where the plants of Ceat Specialty Tyres are located) has imposed a lockdown, but for industrial units like Ceat, "the government has granted a special exemption."

"We are following all the laid-out protocols and ensuring that all our plants are operating at optimum capacity, with the endeavor of serving our customers in the best way possible," said Vijay Gambhire, CEO of Ceat Specialty Tyres.

Ceat Specialty Tyres is a division that makes off-the-road tires, including agricultural and industrial tires sold in North America.

"We are working with the government and various support organizations to help the community in fighting the pandemic."

BKT said it is relying on flexibility to make it through the latest wave to hit India.

"As a resilient organization, we have extensive experience in

planning for and responding to a wide variety of situations," Poddar wrote. "Our teams are closely monitoring developments in the coronavirus (COVID-19) outbreak and are taking the appropriate steps to help maintain the ongoing health and safety of our employees and customers."

He also indicated BKT continues to put "customers first, in teaming and working together for the best outcomes, in deciding and acting in a way that makes an impact, and in learning and adapting so that we can help our employees and customers adjust to this situation."

Sun-TWS factories in India continue to operate at 100 percent capacity, according to Ken Cooper, senior vice president of the company's North America operations, but the latest wave of COVID-19 certainly is impacting the company and the entire country.

Sun-TWS, which has four off-the-road tire plants in India, has instituted a variety of safety precautions allowing manufacturing to continue, he said.

"They test the factory workers every day and throughout the day for temperatures. They've put a lot of (physical) divisions within the plant to separate the workers," Cooper said on May 14. "We are maintaining as big of a distance as possible within the plants."

Sun-TWS routinely disinfects its facilities to help keep its workers safe, he said.

"The biggest impact that it's made is that all the upper management are still at home. They are talking to each other online, or on the phone or in Zoom meetings. Most of the non-essential office people are at home. Some of the essential office people are at work, but they are very distanced," Cooper said.

Employees are being given as much time off as they need to attend funerals or help with the care of sick family members, he added.

"I would say there is not one person within the white-collar part, both the white collar and blue collar, that hasn't had a family member die because of this pandemic. It's been really rough in India as you well know," he said.

Sun-TWS has about 800 employees, including about 400 at four factories in India. The Chennai, India-based company also operates three factories in Sri Lanka that have not been as impacted as much by COVID-19 compared with India facilities, Cooper said.

The senior vice president is based at the company's North America headquarters in Dalton, Ga., where Sun Tyre also has a warehouse. Sun-TWS also has a warehouse in Los Angeles.

Sun-TWS factories in Sri Lanka also have instituted safety precautions including temperature checks, but those locations have not needed to install physical bar-

riers between employees, he said.

While the COVID-19 virus has not directly caused work to slow in India at this point, there have been some indirect challenges due to transportation difficulties being experienced around the world.

Sun-TWS relies on steel imported from China for its products and there has been some difficulty with that supply chain. Other raw materials needed for the company's OTR tires are sourced domestically.

While both BKT and Sun-TWS said they are overcoming COVID-19 related issues, there is another problem that is impacting operations.

"We are experiencing tremendous problems just like everybody else," Cooper said about Sun-TWS, "but they are not as much COVID-related as they are this port situation. We are struggling just like everybody else to get containers shipped and arrived on time. But that has nothing to do with COVID."

Poddar added raw material issues and container availability "are two major factors contrasting with our production/shipping plans."

He said he was motivated to write the letter "to assure you about production and business continuity at our end; and to alert you of any misleading or fake rumors being spread."

While Apollo Tyres did not respond for comment, the company did indicate in a May 20 stock market filing that its Preambra plant was scheduled to resume operations May 21.

The facility previously had been directed to close by district government officials and company officials earlier expected to reopen May 23. Permission to resume two days earlier was then granted by the government.

Technical

FKM

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dioxide in the formulation. But using calcium hydroxide by itself tends to produce a less stable network, thereby negatively affecting physical properties. Addition of magnesium oxide helps to stabilize the network and gives consistent physical properties.

Finally, it is important to recognize that metal oxides are an essential part of the cure system and influence the cure rate and

final physical properties. Changing these levels in the later stages of formulation development (i.e. trying to match a cycle time) may have unintended consequences on final physical properties. Thus, all efforts should be made to match not only the final physical properties, but also the desired cycle times during the initial stages of the formulation development process.

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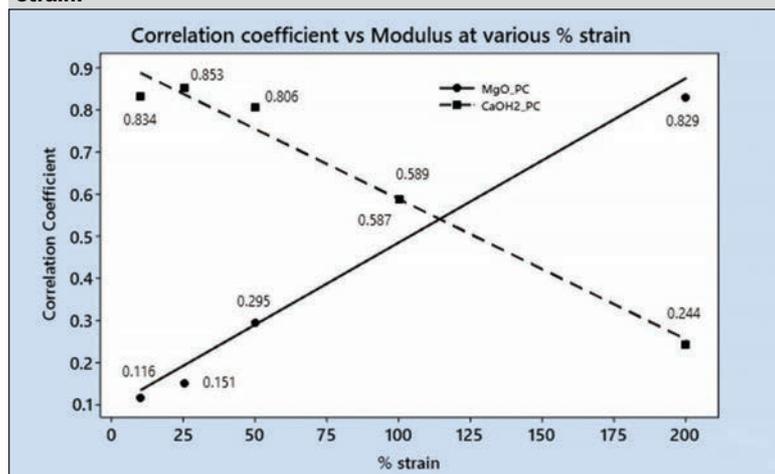
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Table 5: Compression set and correlation coefficients.

FKM#	MgO	Ca(OH) ₂	Compression set		MgO	Ca(OH) ₂	
			168 hrs. @ 200 °C	70 hrs. @ 250 °C			
83	9	0	20.7	55.4	168 hrs. @ 200 °C	-0.541	0.249
84	9	3	23.5	58.7	70 hrs. @ 250 °C	-0.554	-0.027
85	9	6	25.9	66.3			
86	9	9	27.5	63.0			
87	6	0	23.5	62.6			
88	6	3	22.8	59.3			
89	6	6	27.1	62.0			
90	6	9	29.3	68.5			
91	3	0	26.4	76.7			
92	3	3	25.6	64.0			
93	3	6	26.1	65.9			
94	3	9	25.6	65.6			
95	0	0	-	-			
96	0	3	39.1	86.5			
97	0	6	28.3	64.1			
98	0	9	26.7	64.4			

Fig. 11: Correlation coefficients for MO and PC modulus at various % strain.



$$r = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}} \quad (a)$$