Neuburg Siliceous Earth

versus

wollastonite and barium sulfate

in peroxide cured FKM

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Hubert Oggermüller

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1 Introduction

Fluoropolymers are generally known for their good resistance to temperature and media. They are therefore the preferred choice in sealant and media-routing applications where the properties of other polymers are no longer sufficient.

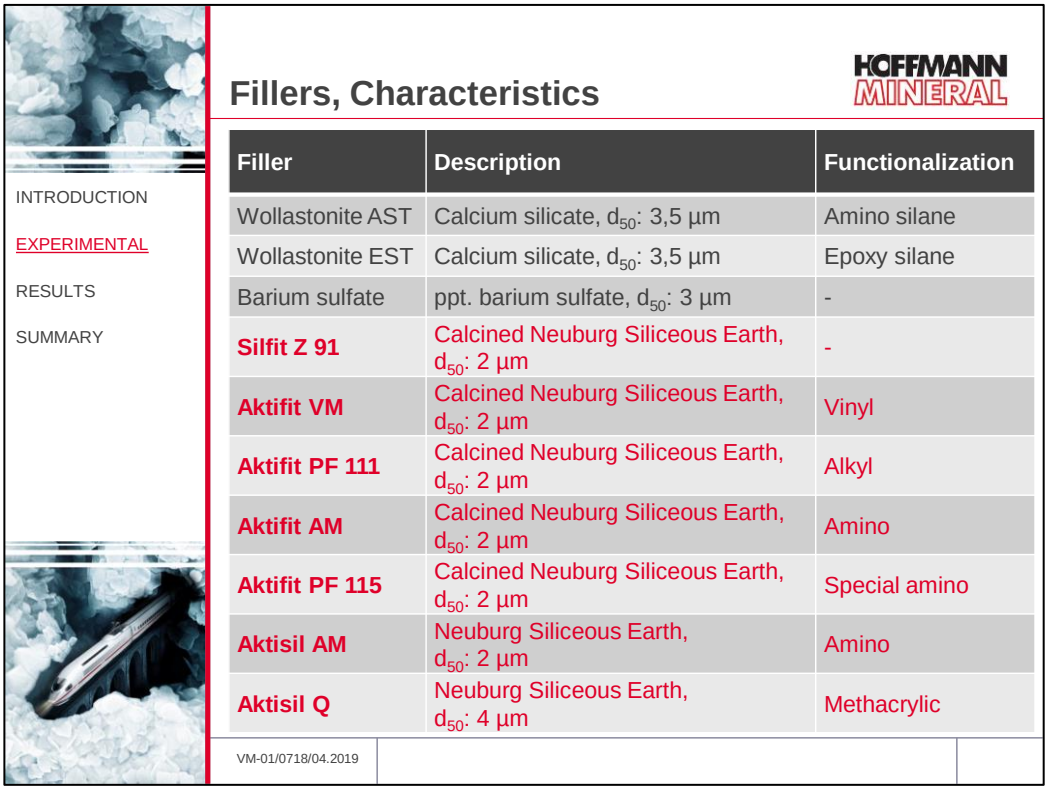
The use of fillers can improve the property profile of a fluoropolymer.

Light mineral fillers are used alongside carbon black N990. Wollastonite and barium sulfate are typical examples of the same.

This paper compares the various types of Neuburg Siliceous Earth (NSE) with these typical examples.

2 Experimental

2.1 Fillers, formulations and compounding



Filler	Description	Functionalization
Wollastonite AST	Calcium silicate, d_{50}: 3,5 µm	Amino silane
Wollastonite EST	Calcium silicate, d_{50}: 3,5 µm	Epoxy silane
Barium sulfate	ppt. barium sulfate, d_{50}: 3 µm	-
Silfit Z 91	Calcined Neuburg Siliceous Earth, d_{50}: 2 µm	-
Aktifit VM	Calcined Neuburg Siliceous Earth, d_{50}: 2 µm	Vinyl
Aktifit PF 111	Calcined Neuburg Siliceous Earth, d_{50}: 2 µm	Alkyl
Aktifit AM	Calcined Neuburg Siliceous Earth, d_{50}: 2 µm	Amino
Aktifit PF 115	Calcined Neuburg Siliceous Earth, d_{50}: 2 µm	Special amino
Aktisil AM	Neuburg Siliceous Earth, d_{50}: 2 µm	Amino
Aktisil Q	Neuburg Siliceous Earth, d_{50}: 4 µm	Methacrylic

Fig. 1

Silfit Z 91 was chosen as a calcined variant of Neuburg Siliceous Earth without surface treatment.
The grades Aktifit VM, Aktifit PF 111, Aktifit AM and Aktifit PF 115 are based on Calcined Neuburg Siliceous Earth and have been surface treated with the functional group listed in Fig. 1.

Aktisil AM and Aktisil Q are derivatives of conventional NSE types, although the latter is based on a somewhat coarser Neuburg Siliceous Earth.

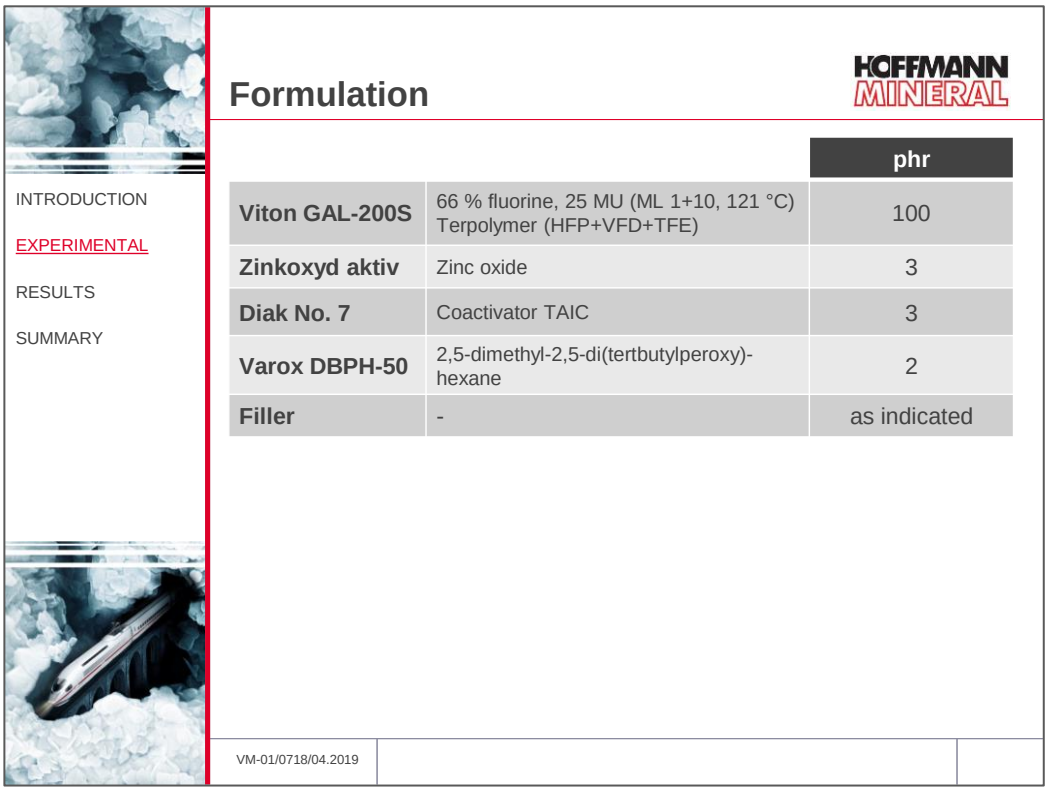
The NSE grades are compared with wollastonite types AST – treated with aminosilane – and EST – treated with epoxysilane.
A comparison is also shown with precipitated barium sulfate.

The formulation (Fig. 2) shows the typical structure of a peroxide-cured FKM compound with zinc oxide, coagent and peroxide.

The same loading – 30 phr – was used for both wollastonite and the NSE grades, while 49 phr was chosen for the barium sulfate (to achieve equal dosage by volume of the barium sulfate which has a higher density). This produced vulcanizates with the same hardness ranging between 65 and 70 Shore A.

Compounding was performed on a laboratory mill (Schwabenthan Polymix 150 L). The polymer was applied to the mill at 50°C and rolled into even sheets. After incorporation of the zinc oxide, the filler was added. To ensure the even distribution of the compound ingredients, the compound was rolled 10 times. Given the stickiness on the roller surface, the rollers were cooled down to 30°C for this process. The compounds were typically mixed for 15 minutes.

Vulcanization in the press was performed at 177 °C for 7 minutes. Post-cure was conducted 2 hours at 232 °C.



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Formulation

HOFFMANN MINERAL

		phr
Viton GAL-200S	66 % fluorine, 25 MU (ML 1+10, 121 °C) Terpolymer (HFP+VFD+TFE)	100
Zinkoxyd aktiv	Zinc oxide	3
Diak No. 7	Coactivator TAIC	3
Varox DBPH-50	2,5-dimethyl-2,5-di(tertbutylperoxy)-hexane	2
Filler	-	as indicated

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Fig. 2

2.2 Tests

The results shown here relate to post-cured test specimens unless otherwise indicated.

Along with measuring the hardness, tensile tests were performed and the compression set examined.

Media resistance was examined as follows:

- Hot air — 94 hours / 230°C
  504 hours / 210°C
- Engine oil OS206304 — 168 hours / 150°C
- Fuel FAM B (DIN 51604) — 70 hours / 23°C
- Acetic acid (1M, pH 3) — 168 hours / 100°C

Aging in acetic acid was aimed at simulating blow-by resistance.

The results of all examined compounds and all tests can be found in tabular form at the end of this report.

3 Results

3.1 Neuburg Siliceous Earth versus Wollastonite AST

3.1.1 Rheological properties

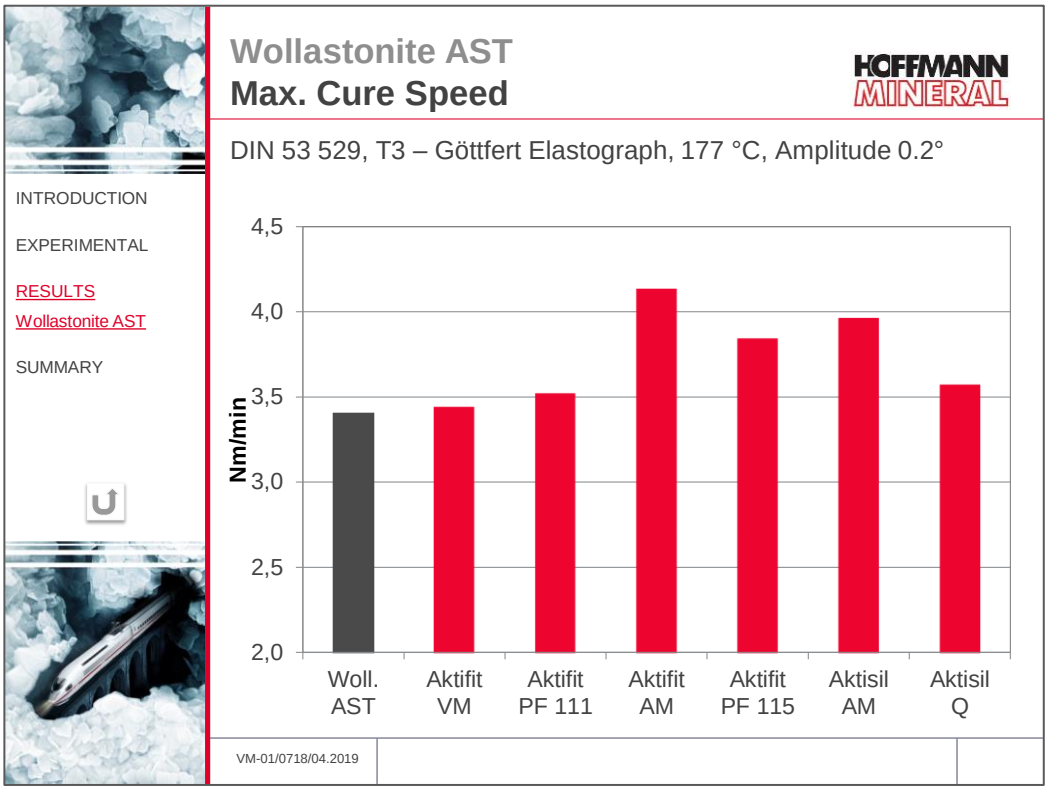


Fig. 3

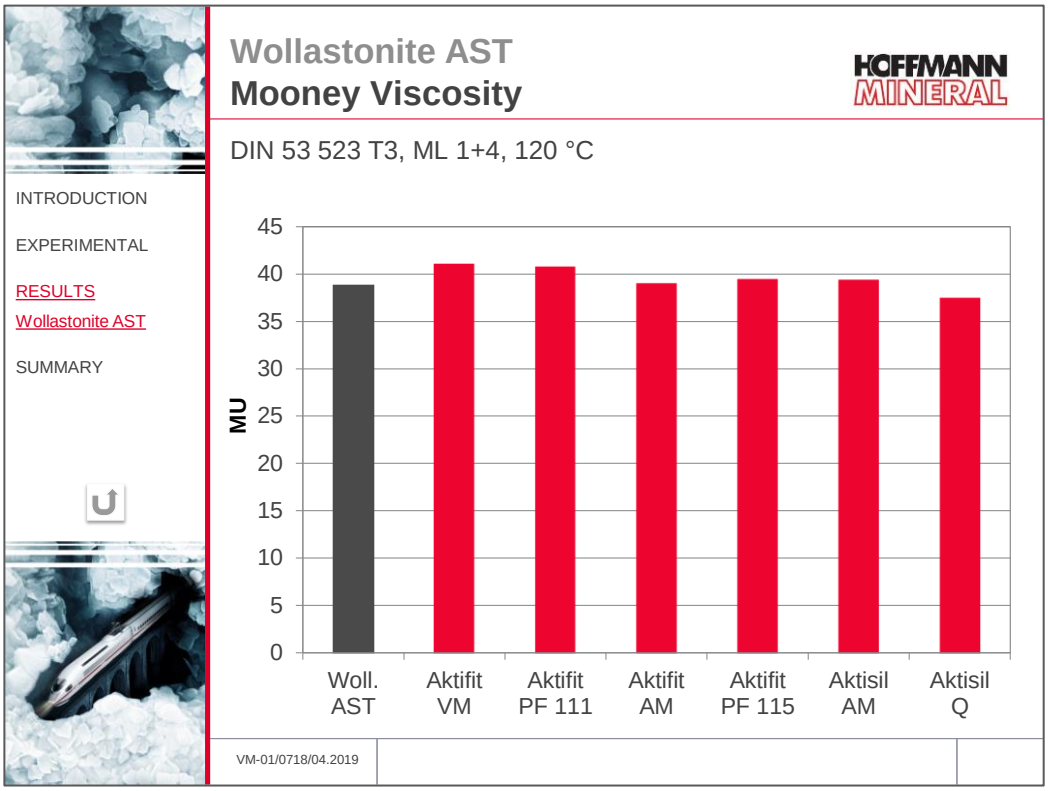


Fig. 4

The amino functional NSE grades Aktifit AM, Aktifit PF 115 and Aktisil AM enable a faster curing speed than the aminosilane-treated wollastonite (Fig. 3). The viscosity of the compounds is comparable across the board (Fig. 4).

3.1.2 Mechanical properties

All NSE grades raise tensile strength compared to the aminosilane-treated wollastonite (Fig. 5). At the same time, the good elongation at break performance is maintained, e.g. with Aktifit PF 111, Aktifit AM and Aktifit PF 115 (Fig. 6). The resulting moduli at 100 % elongation are shown in Fig. 7.

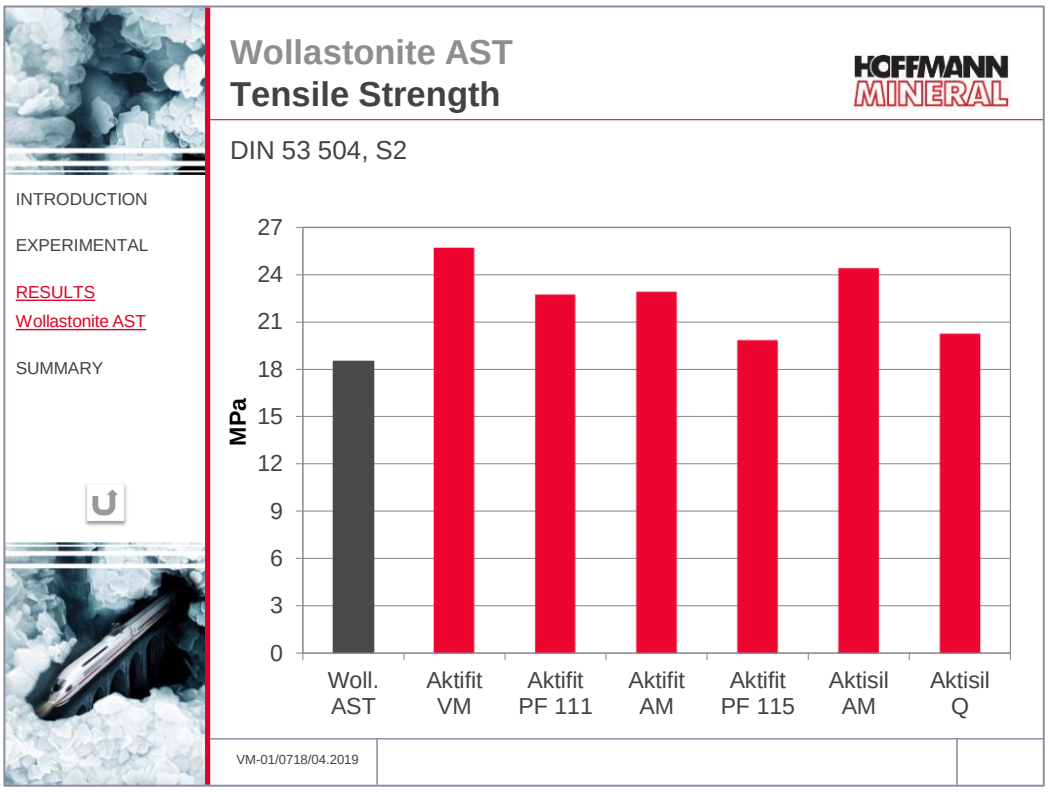


Fig. 5

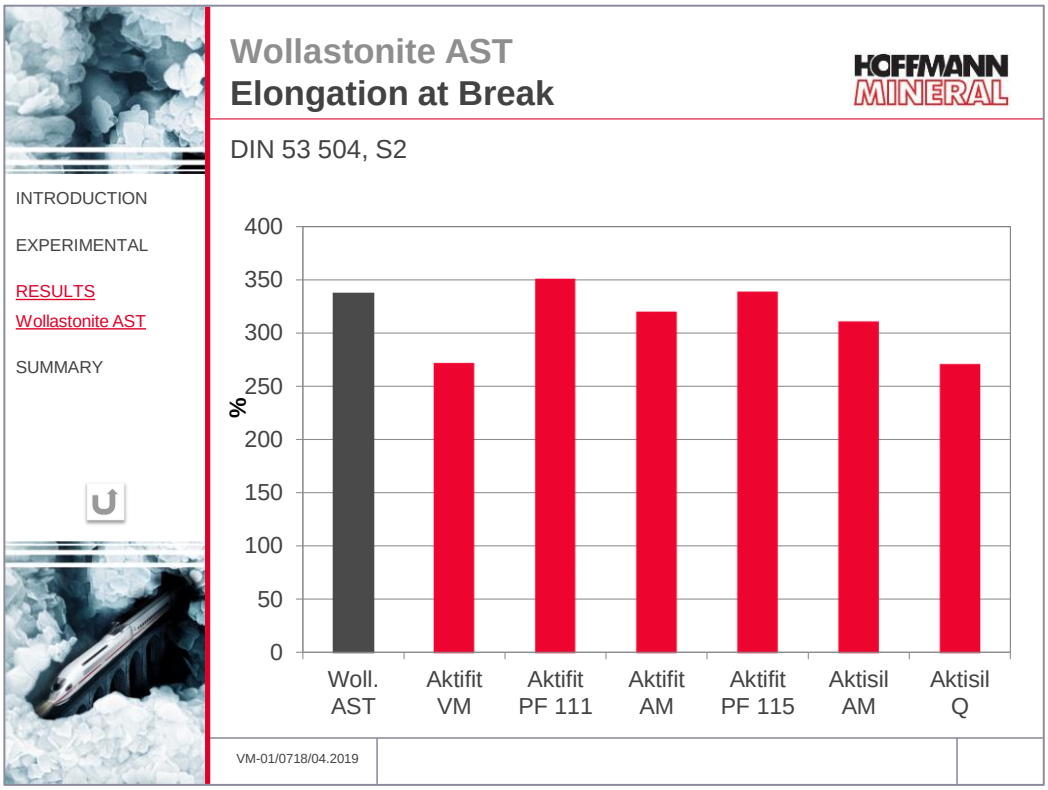


Fig. 6

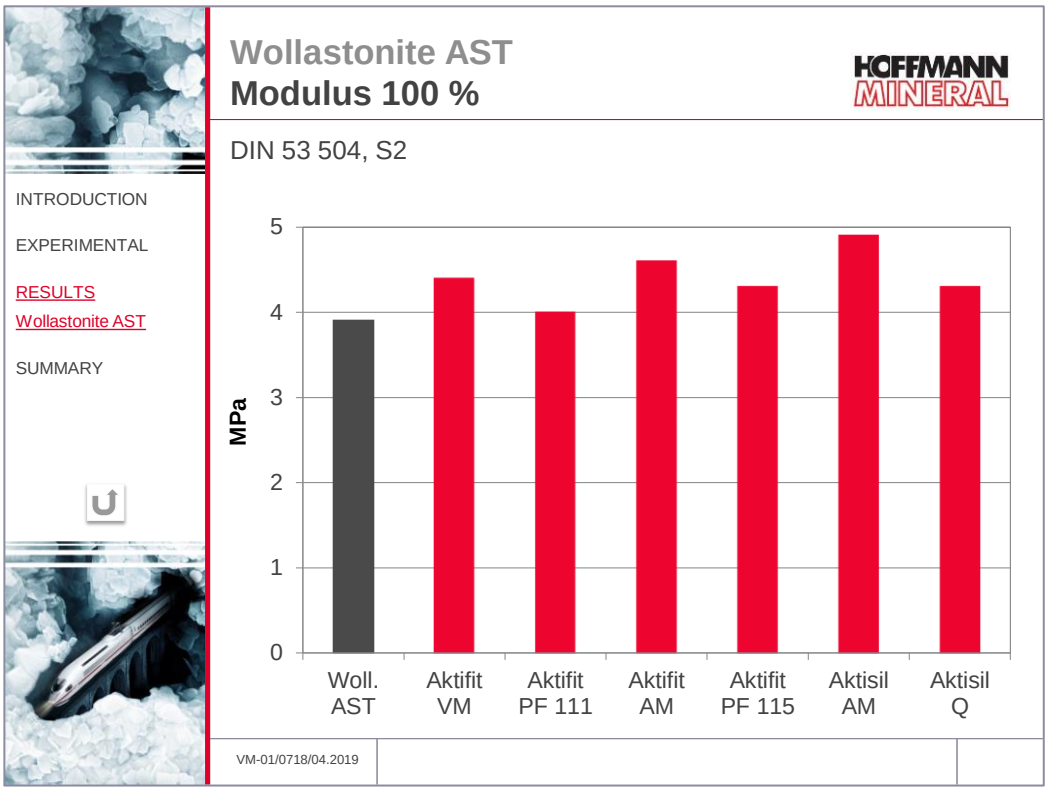


Fig. 7

By replacing the aminosilane-treated wollastonite with Neuburg Siliceous Earth, it proves to be possible to reduce the compression set. Fig. 8 shows the compression set as per DIN ISO 815-1 B after 70 hours at 232 °C. The marked improvement with Aktifit VM, Aktifit PF 111 and especially Aktisil Q is clearly apparent. Aktisil Q, in particular, offers the benefit of significantly reducing compression set even on test specimens, that have not been post-cured.

If VW's compression set as per PV 3307 is important, the use of Aktisil AM is recommended as it results in the best value at room temperature (Fig. 9).

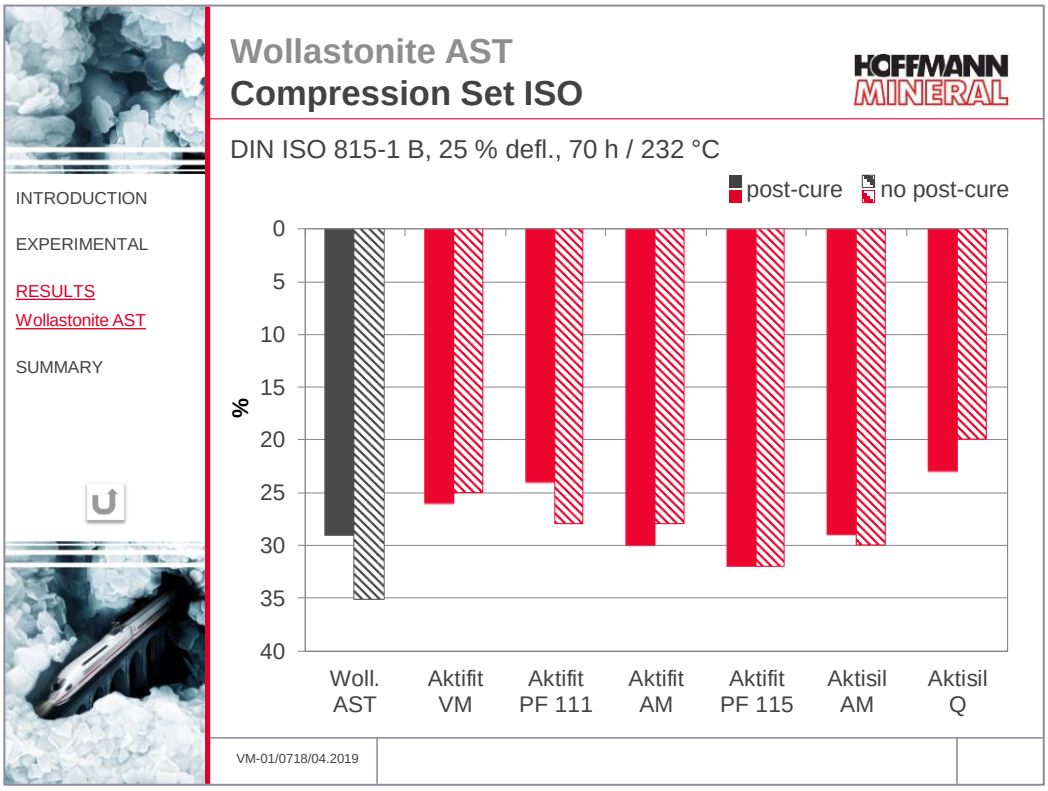


Fig. 8

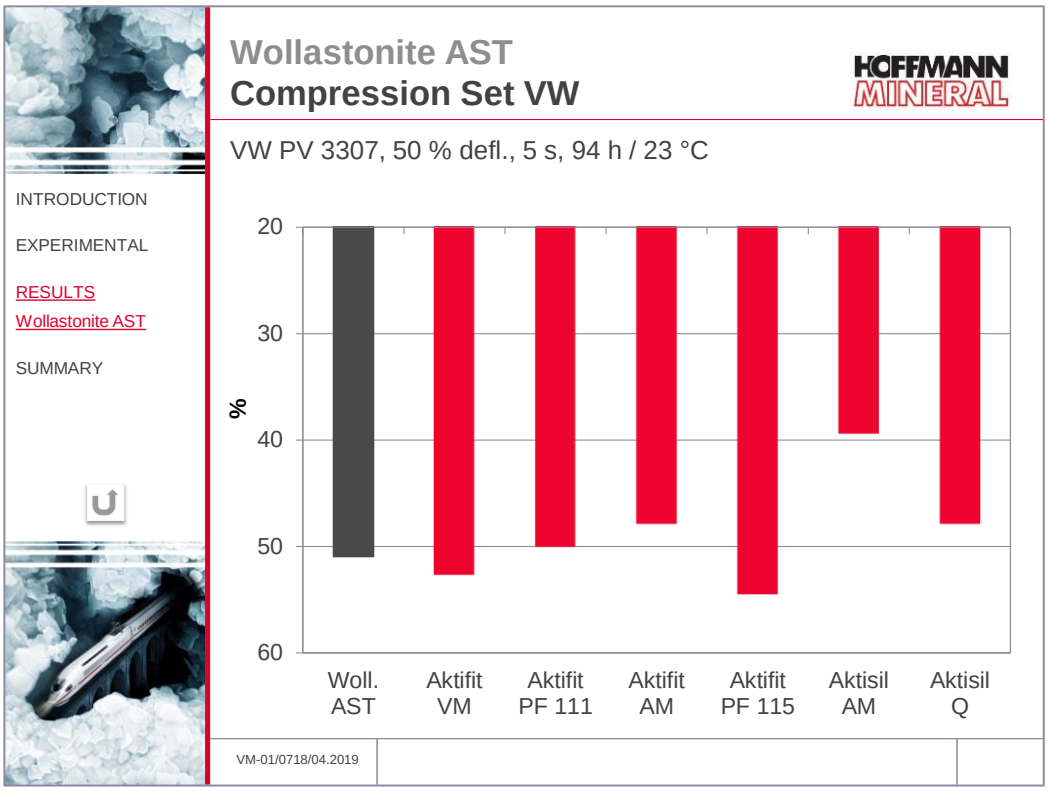


Fig. 9

If abrasion resistance of the component is important, replacing the aminosilane-treated wollastonite with any of the tested NSE types produces a significant improvement (Fig. 10)

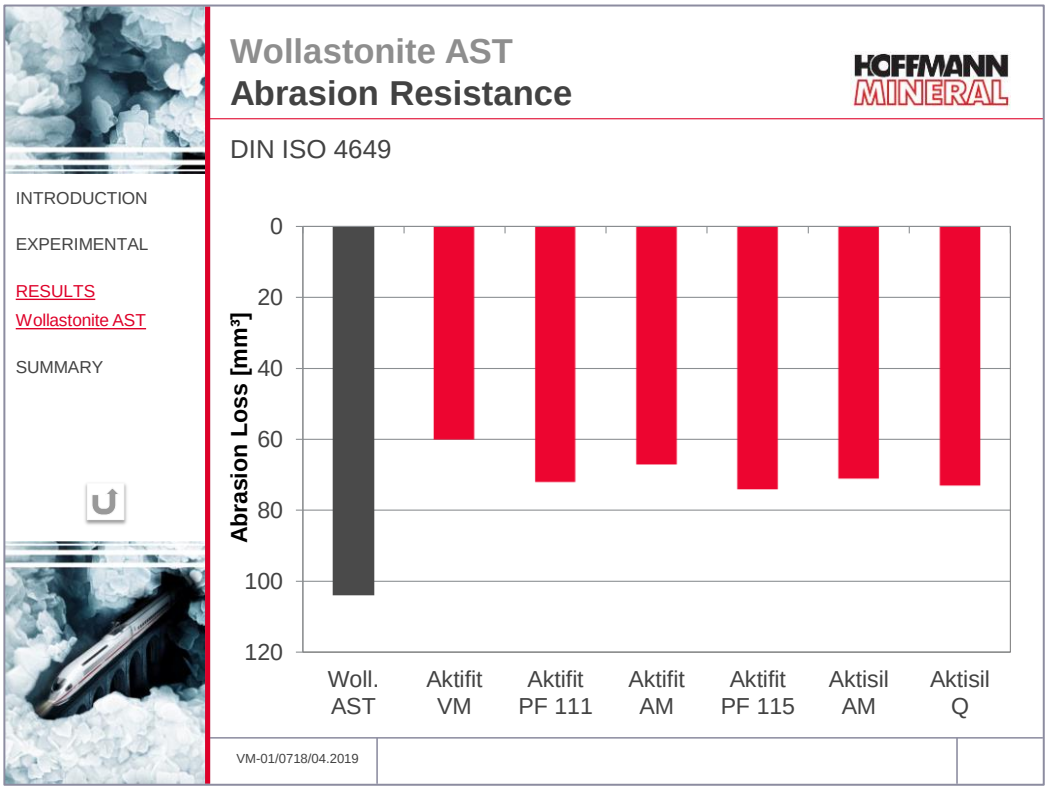


Fig. 10

3.1.3 Media resistance

3.1.3.1 Resistance to hot air and fuel

The changes in mechanical properties after aging in hot air or fuel are comparable across the board. The higher tensile strength and comparable elongation at break of the vulcanizates filled with Neuburg Siliceous Earth are maintained versus the aminosilane-treated wollastonite.

3.1.3.2 Resistance to oil

An analysis of the changes in tensile strength and elongation at break after aging in engine oil (Fig. 11) clearly shows the benefits of using Aktifit AM or Aktisil Q. Compared to the wollastonite, they demonstrate the least reduction in mechanical properties and sustain unchanged high tensile strength (Fig. 12).

The influence of oil immersion on hardness is also virtually non-existent when using Neuburg Siliceous Earth, as clearly shown in Fig. 13.

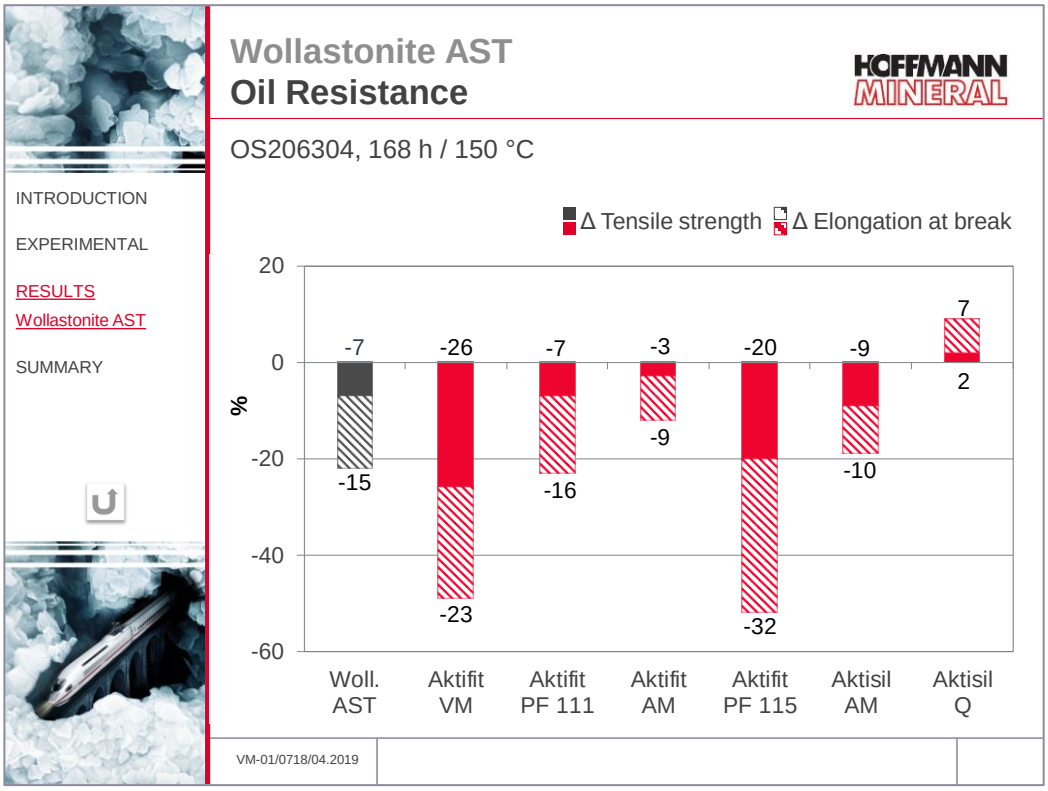


Fig. 11

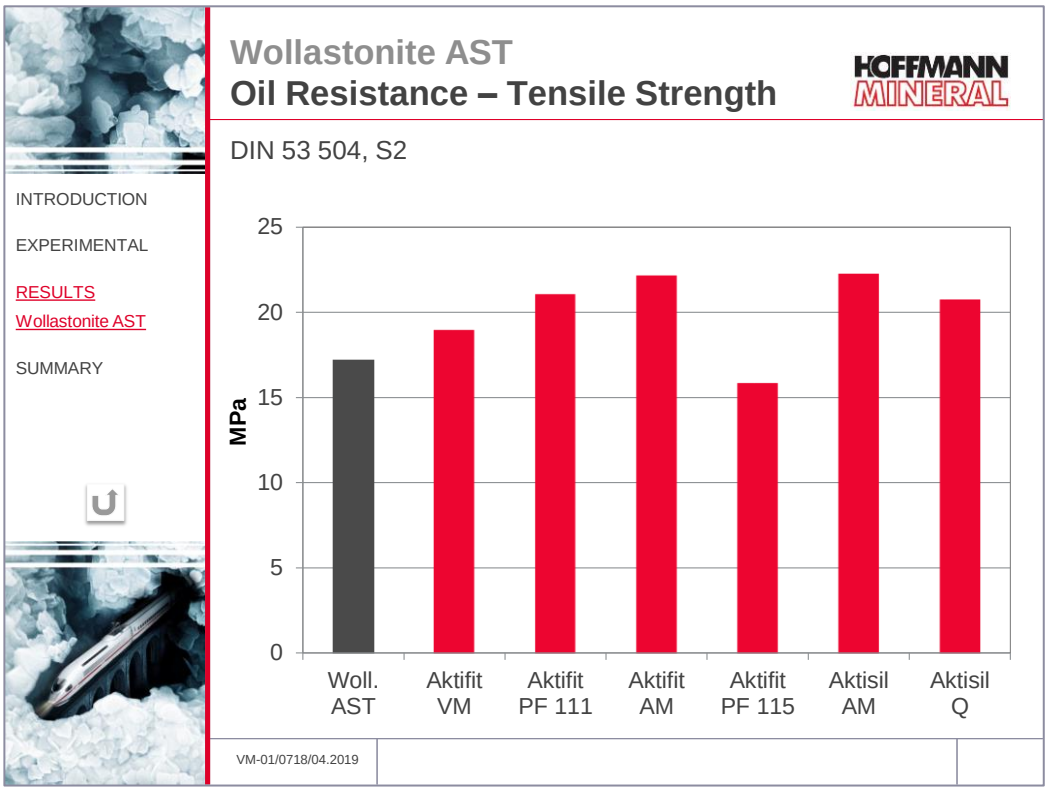
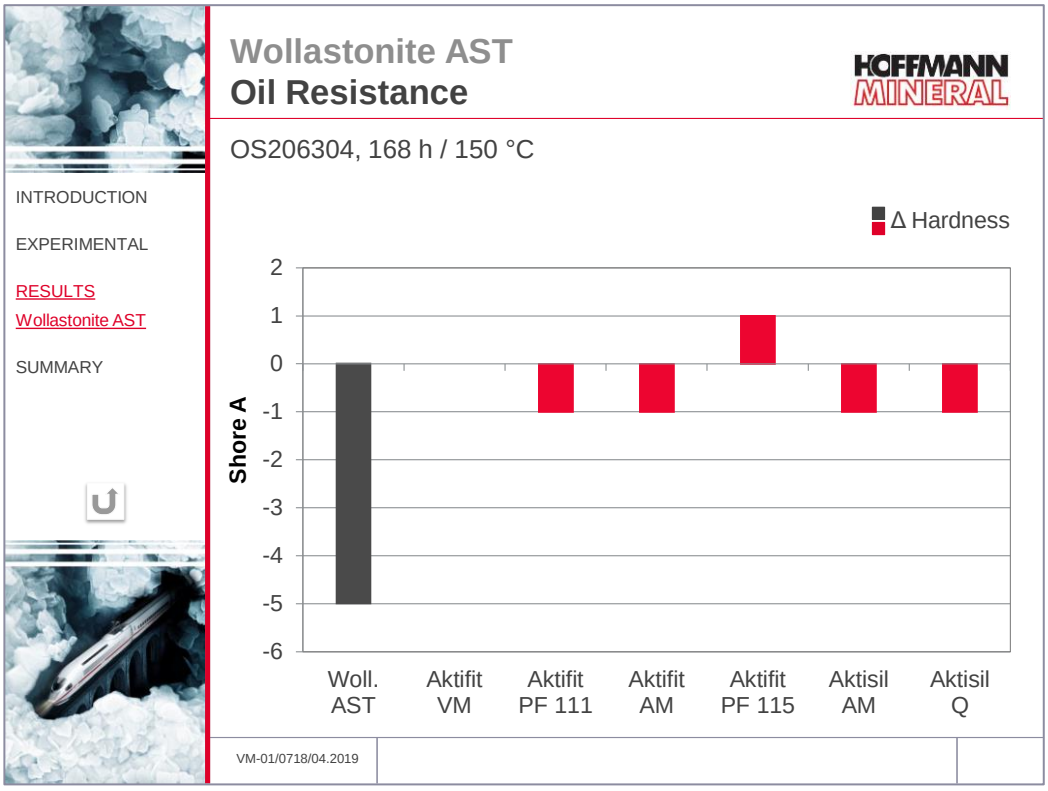

Wollastonite AST
Oil Resistance – Tensile Strength
HOFFMANN MINERAL
DIN 53 504, S2
INTRODUCTION
EXPERIMENTAL
RESULTS
Wollastonite AST
SUMMARY
MPa
25
20
15
10
5
0
Woll. AST
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
VM-01/0718/04.2019

Fig. 12


Wollastonite AST
Oil Resistance
HOFFMANN MINERAL
OS206304, 168 h / 150 °C
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RESULTS
Wollastonite AST
SUMMARY
Δ Hardness
Shore A
2
1
0
-1
-2
-3
-4
-5
-6
Woll. AST
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
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Fig. 13

3.1.3.3 Resistance to acid

Replacing the aminosilane-treated wollastonite with Neuburg Siliceous Earth makes the vulcanizates resistant to acetic acid. This is verified both by the changes in tensile strength, elongation at break (Fig. 14) and hardness (Fig. 15), and by the increase in volume of the test specimen (Fig. 16 + Fig. 17).

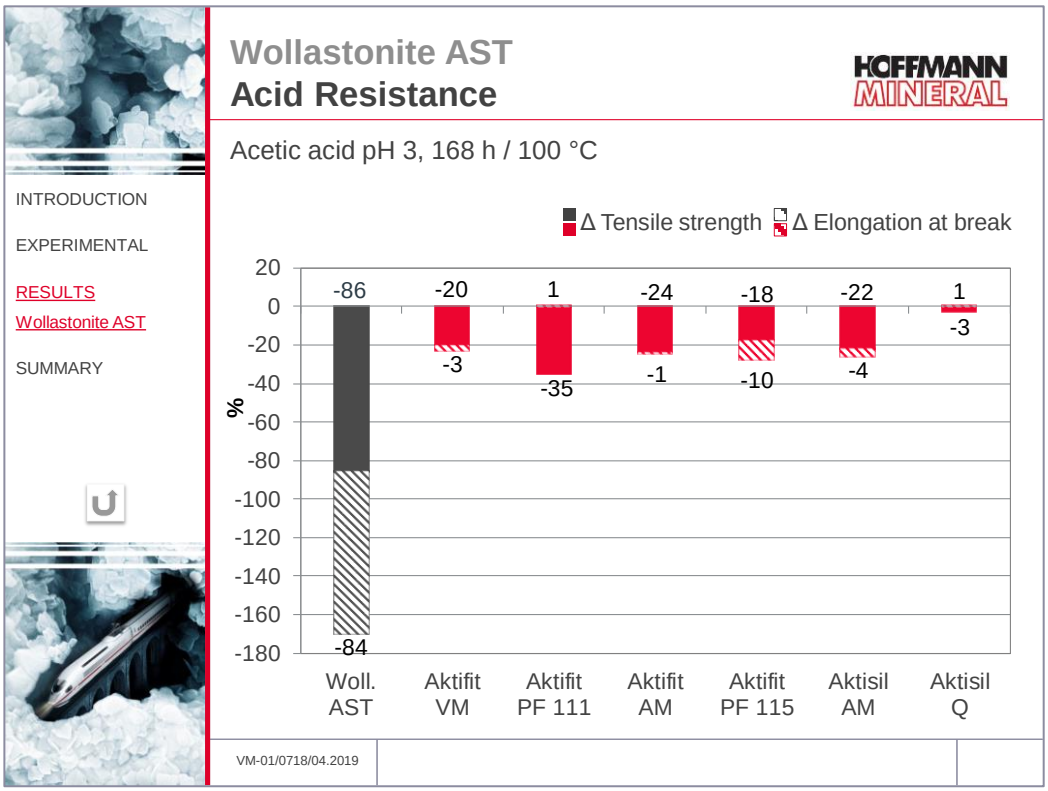


Fig. 14

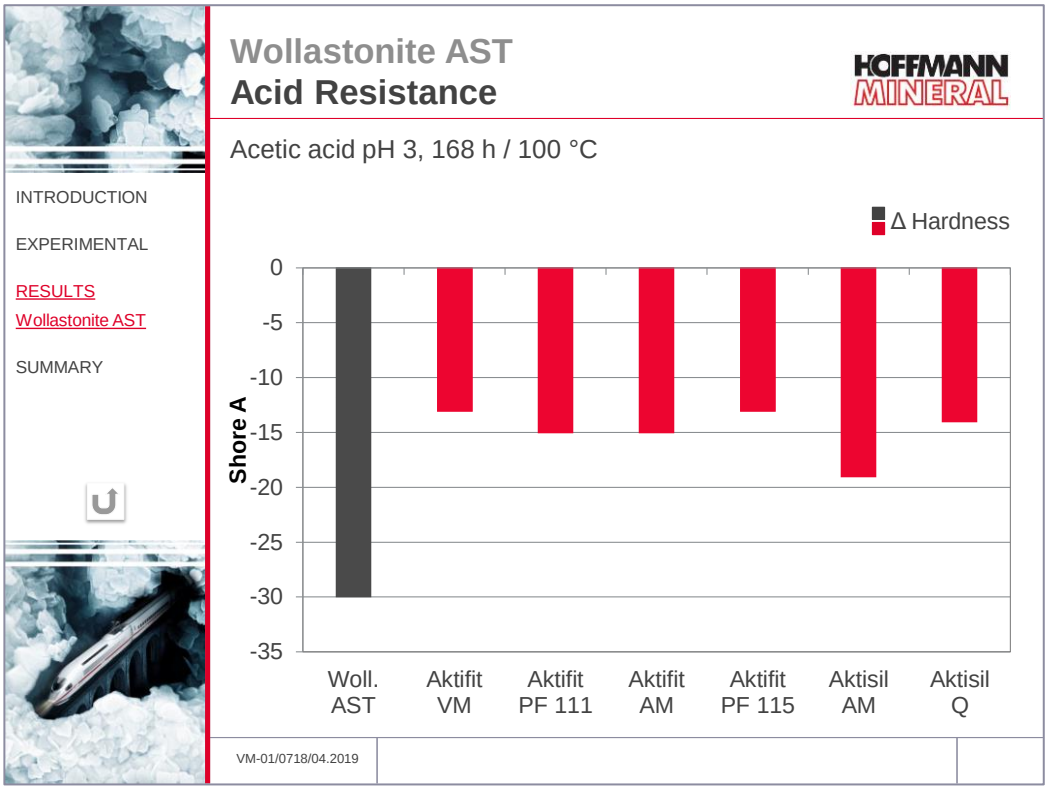


Fig. 15

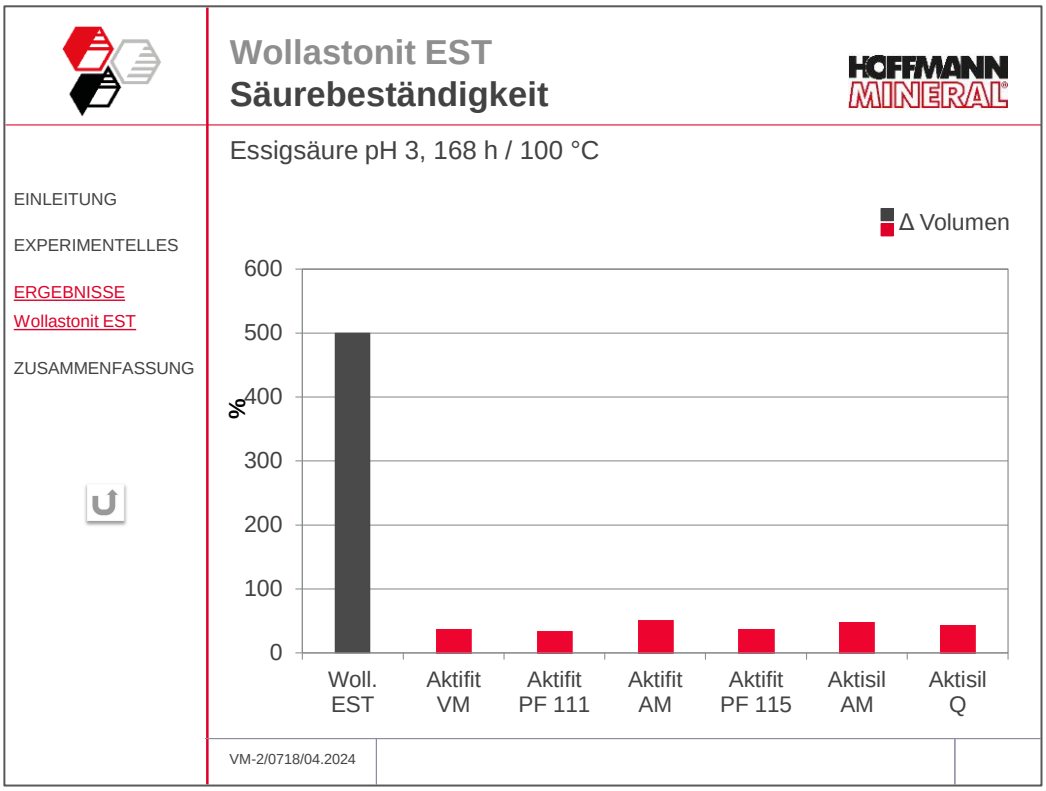
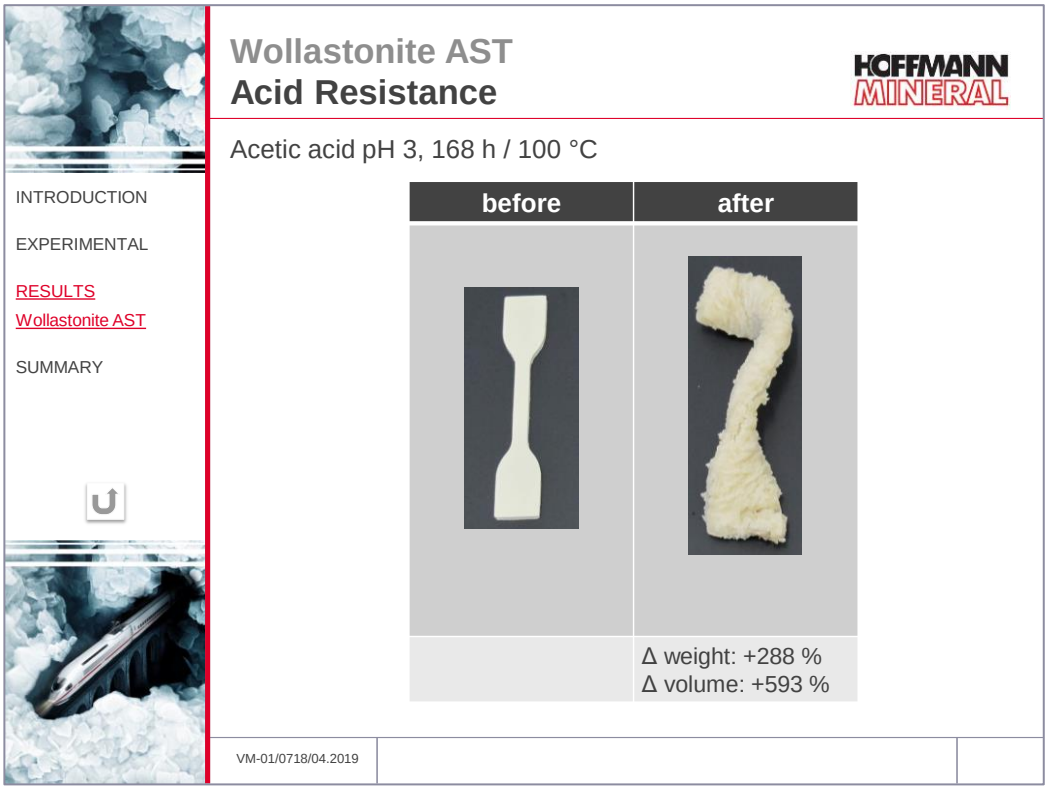

Wollastonit EST
Säurebeständigkeit
HOFFMANN MINERAL
Essigsäure pH 3, 168 h / 100 °C
EINLEITUNG
EXPERIMENTELLES
ERGEBNISSE
Wollastonit EST
ZUSAMMENFASSUNG
Δ Volumen
%
600
500
400
300
200
100
0
Woll. EST
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
VM-2/0718/04.2024

Fig. 16


Wollastonite AST
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
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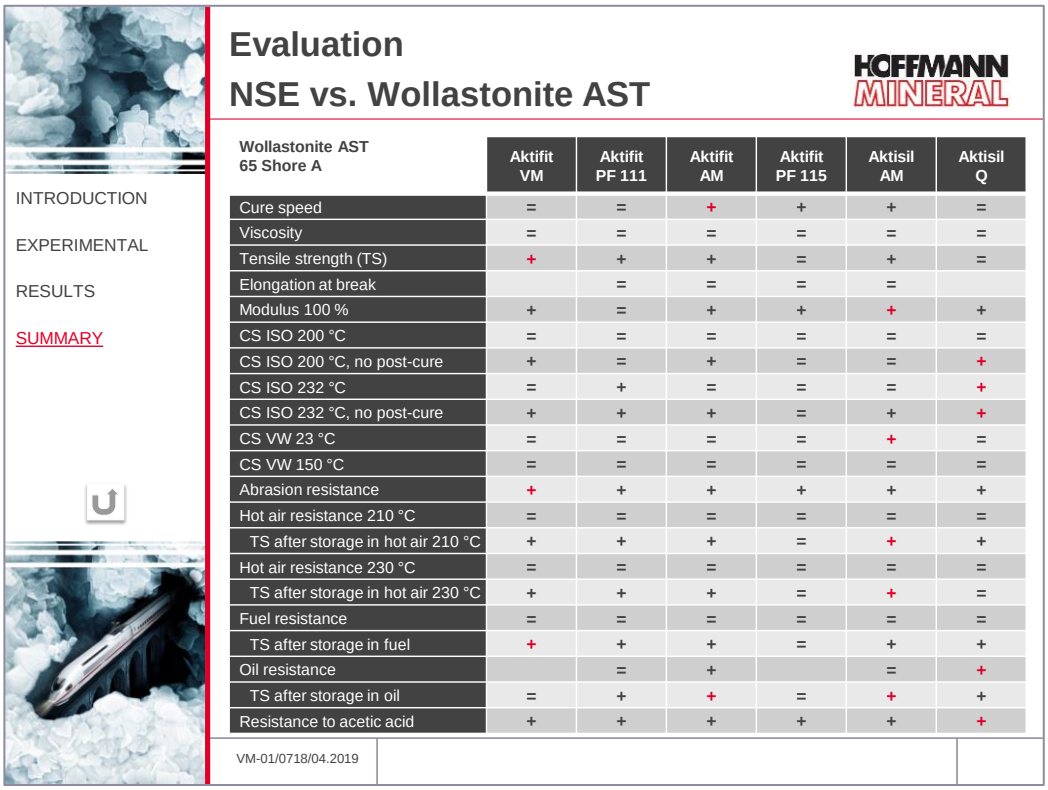
Wollastonite AST
SUMMARY
before
after
Δ weight: +288 %
Δ volume: +593 %
VM-01/0718/04.2019

Fig. 17

3.1.4 Evaluation of the results

Various properties and combinations of properties – often even contradicting properties – are positively influenced by the Neuburg Siliceous Earth products. This is verified in the following summary analysis.



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Evaluation
NSE vs. Wollastonite AST

HOFFMANN MINERAL

Wollastonite AST 65 Shore A	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Cure speed	=	=	+	+	+	=
Viscosity	=	=	=	=	=	=
Tensile strength (TS)	+	+	+	=	+	=
Elongation at break		=	=	=	=	
Modulus 100 %	+	=	+	+	+	+
CS ISO 200 °C	=	=	=	=	=	=
CS ISO 200 °C, no post-cure	+	=	+	=	=	+
CS ISO 232 °C	=	+	=	=	=	+
CS ISO 232 °C, no post-cure	+	+	+	=	+	+
CS VW 23 °C	=	=	=	=	+	=
CS VW 150 °C	=	=	=	=	=	=
Abrasion resistance	+	+	+	+	+	+
Hot air resistance 210 °C	=	=	=	=	=	=
TS after storage in hot air 210 °C	+	+	+	=	+	+
Hot air resistance 230 °C	=	=	=	=	=	=
TS after storage in hot air 230 °C	+	+	+	=	+	=
Fuel resistance	=	=	=	=	=	=
TS after storage in fuel	+	+	+	=	+	+
Oil resistance		=	+		=	+
TS after storage in oil	=	+	+	=	+	+
Resistance to acetic acid	+	+	+	+	+	+

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Fig. 18

Fig. 18 shows which NSE grades either improve (+) or match (=) the relevant property performance versus the aminosilane-treated wollastonite. Red + signs indicate the NSE product that achieves the best result for the appropriate property among NSE grades.

3.2 Neuburg Siliceous Earth versus Wollastonite EST

3.2.1 Rheological properties

Compared to the epoxysilane-treated wollastonite, all of the listed NSE types are able to achieve faster curing speeds, as shown in Fig. 19. The variants with amino functional group achieve the highest levels. Viscosity (Fig. 20) is comparable across the board.

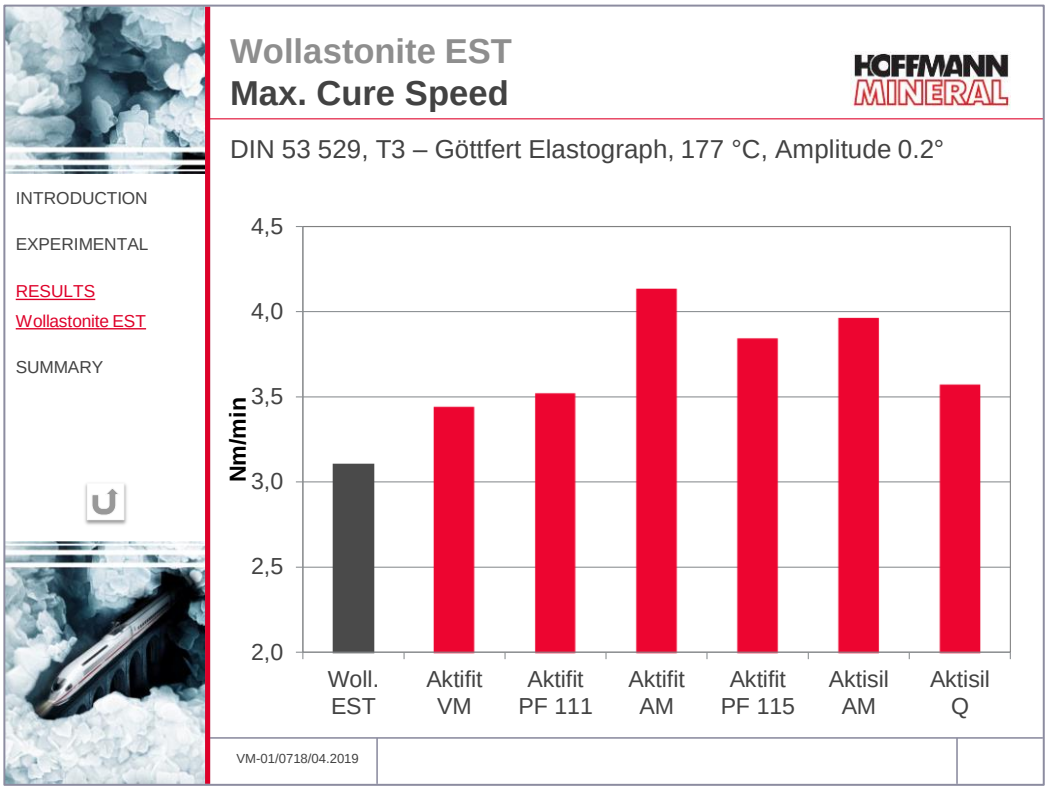

Fig. 19

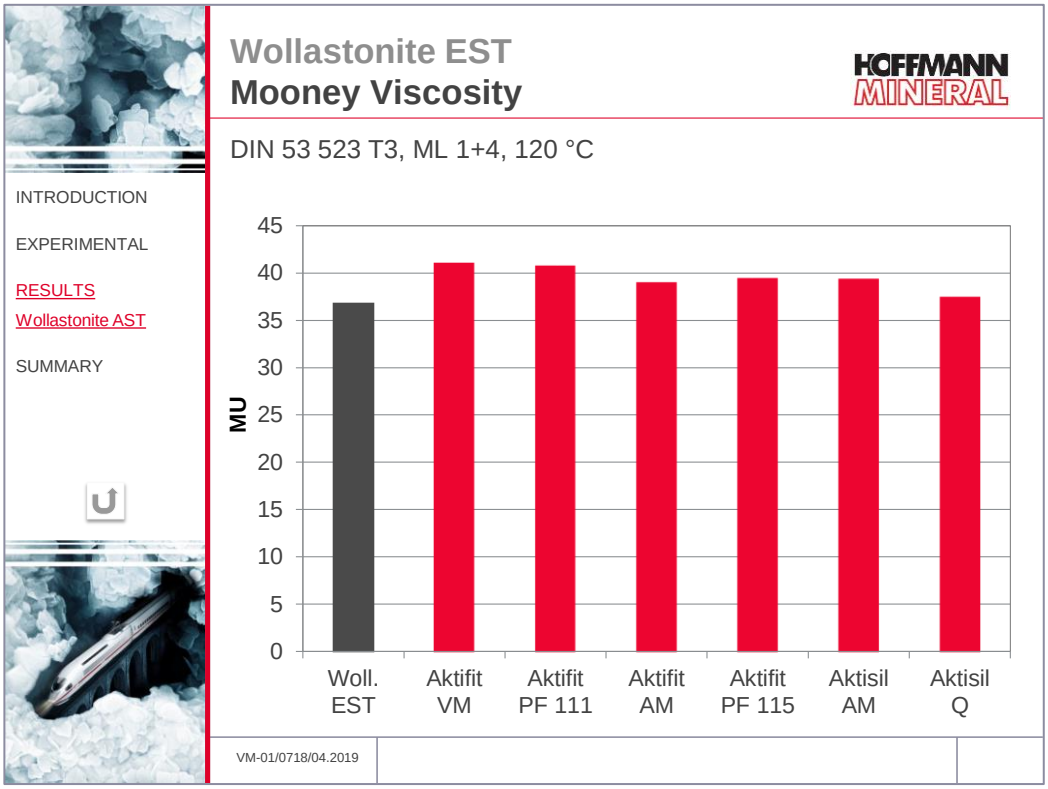

Fig. 20

3.2.2 Mechanical properties

The tensile strength with Aktifit PF 115 and Aktisil Q is comparable to that of the epoxysilane-treated wollastonite (Fig. 21). The other NSE grades all result in higher tensile strength. Equally, the NSE variants are able to raise moduli at 100 % elongation compared to the wollastonite (Fig. 22).

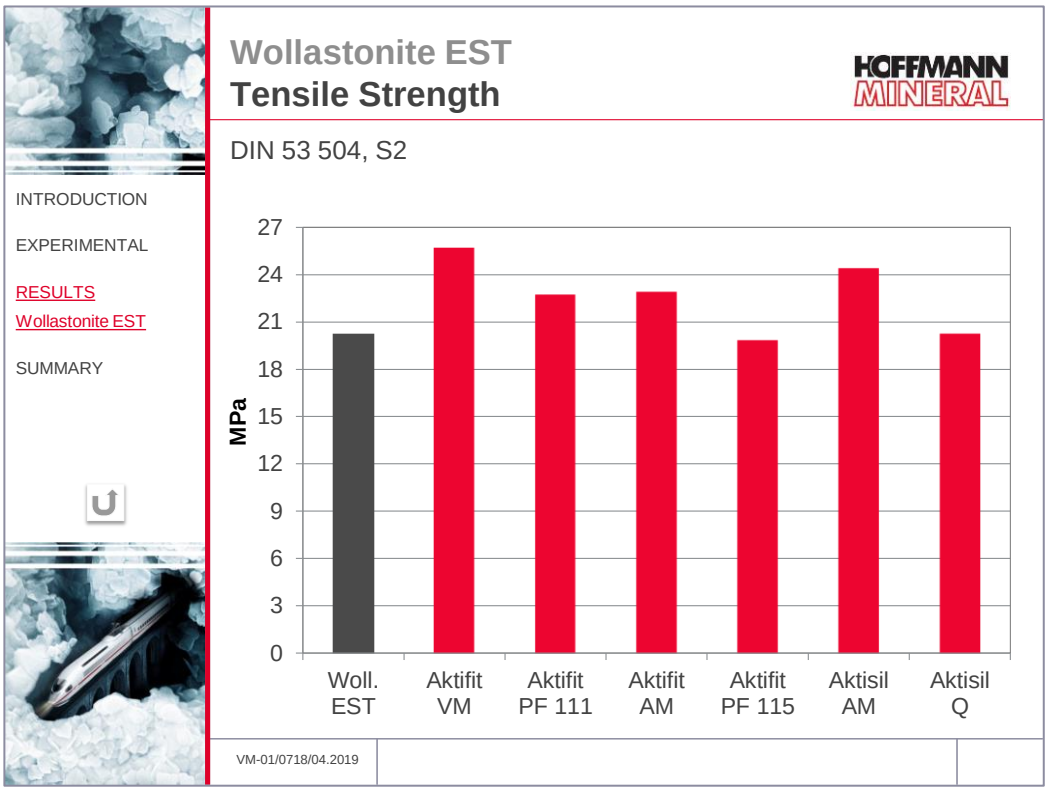

Fig. 21

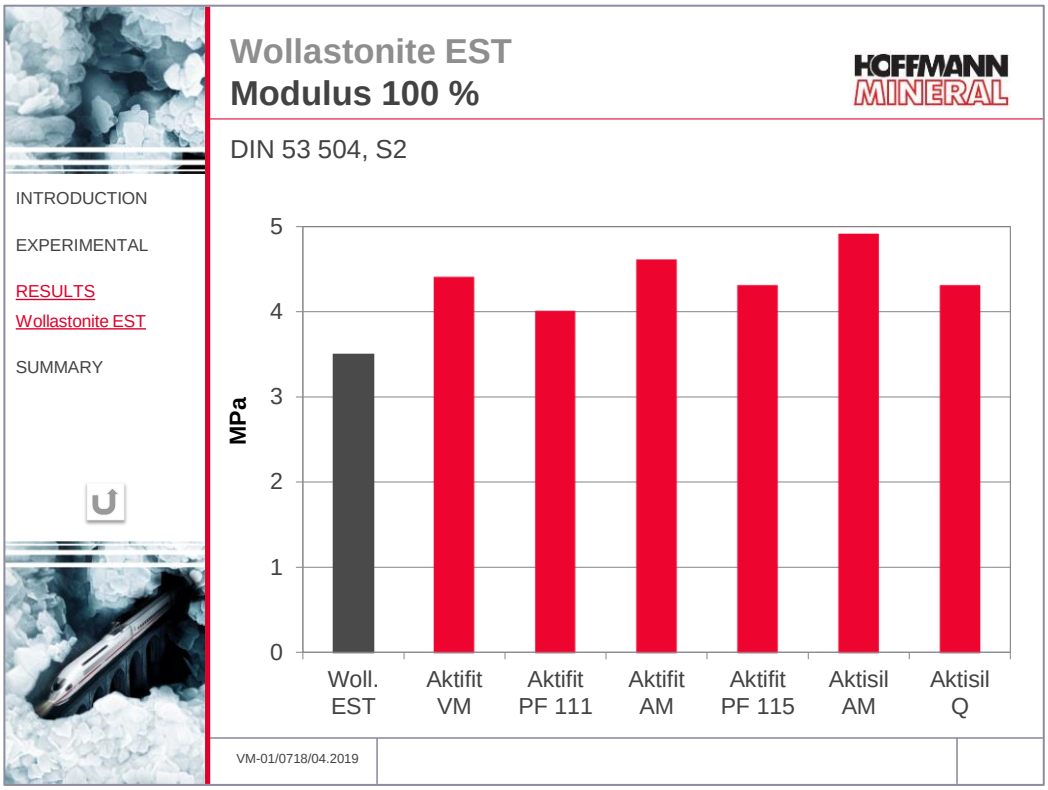

Fig. 22

As far as the compression set is concerned, the performance of the epoxysilane-treated wollastonite is already good (Fig. 23). Aktifit VM, Aktifit PF 111 and Aktisil Q are able to match it. The latter's performance is better than wollastonite if the specimens are not post-cured.

Replacing the wollastonite with Aktisil AM results in a significant reduction in the compression set as measured according to VW test specification PV 3307, as shown in Fig. 24.

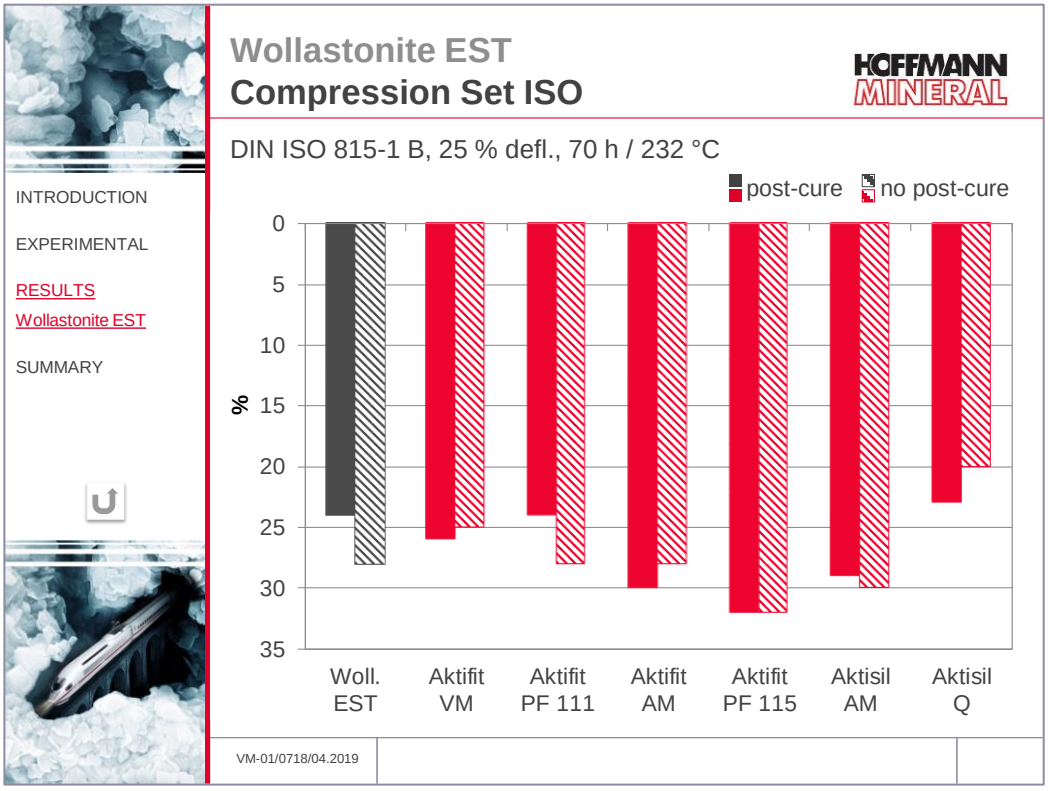

Fig. 23

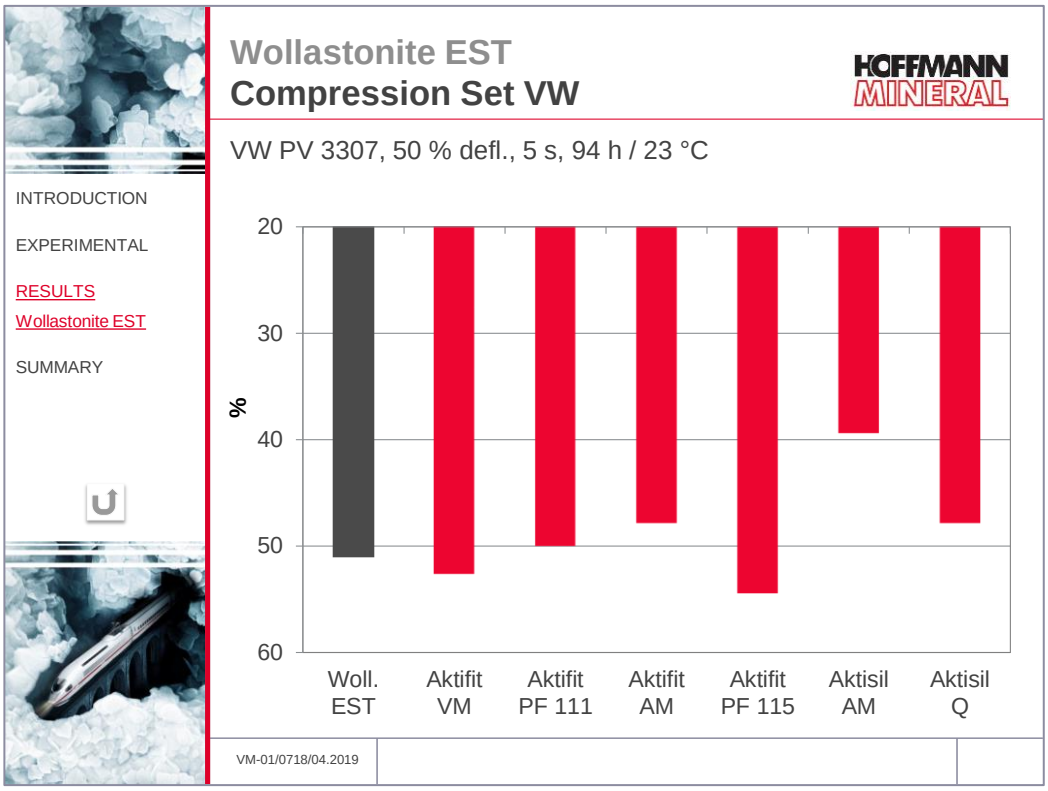

Fig. 24

If applications require improved abrasion resistance, the epoxysilane-treated wollastonite can be replaced with any of the NSE variants addressed in this paper (Fig. 25).

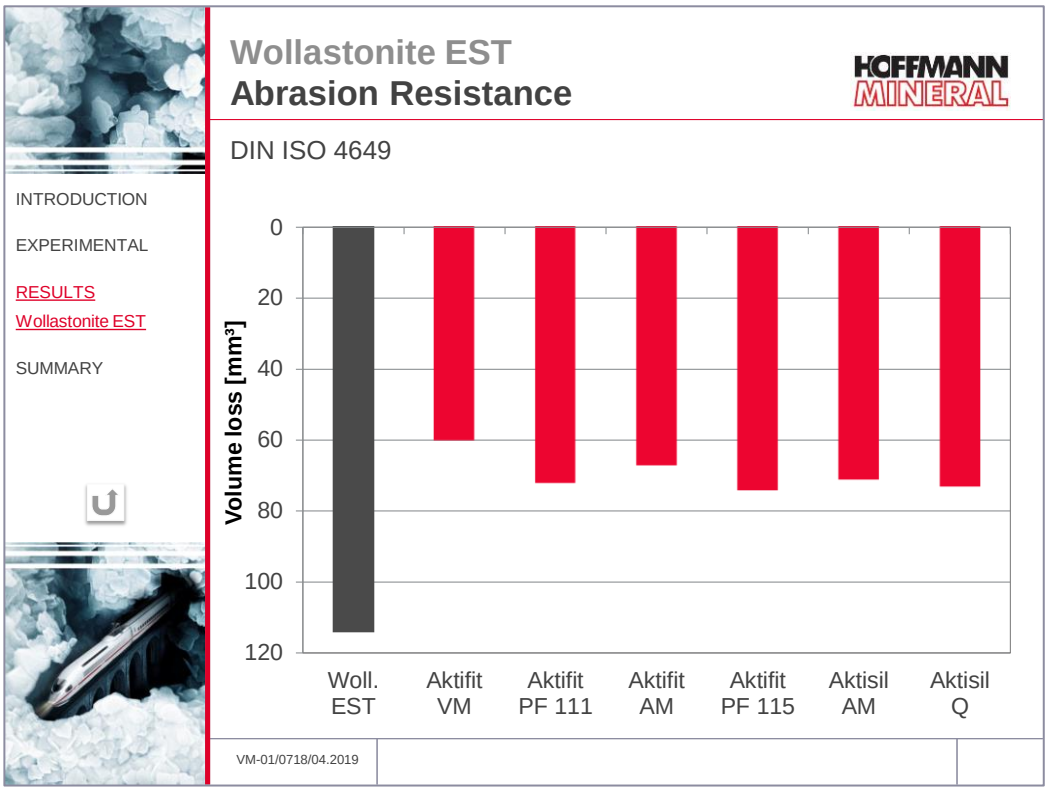

Fig. 25

3.2.3 Media resistance

3.2.3.1 Resistance to hot air and fuel

The changes in mechanical properties after aging in hot air or fuel are comparable across the board. The higher tensile strength of the vulcanizates filled with Neuburg Siliceous Earth are maintained versus the epoxysilane-treated wollastonite.

3.2.3.2 Resistance to oil

With regard to resistance to oil (OS206304), Aktifit PF 111, Aktifit AM, Aktisil AM and Aktisil Q score better than the epoxysilane-treated wollastonite. They lead to much lesser changes in tensile strength and elongation at break after storing the vulcanizates in oil (Fig. 26). As a result, the tensile strength of these NSE variants is nearly 10 MPa better than that of the wollastonite (Fig. 27).

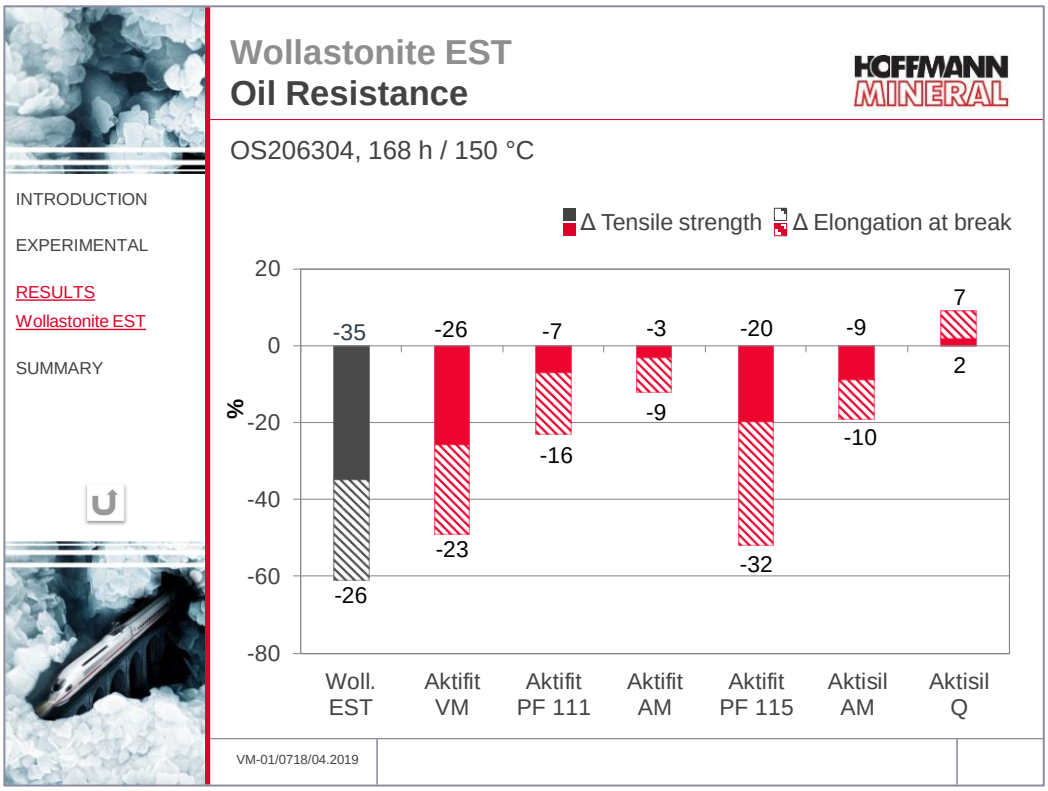

Fig. 26

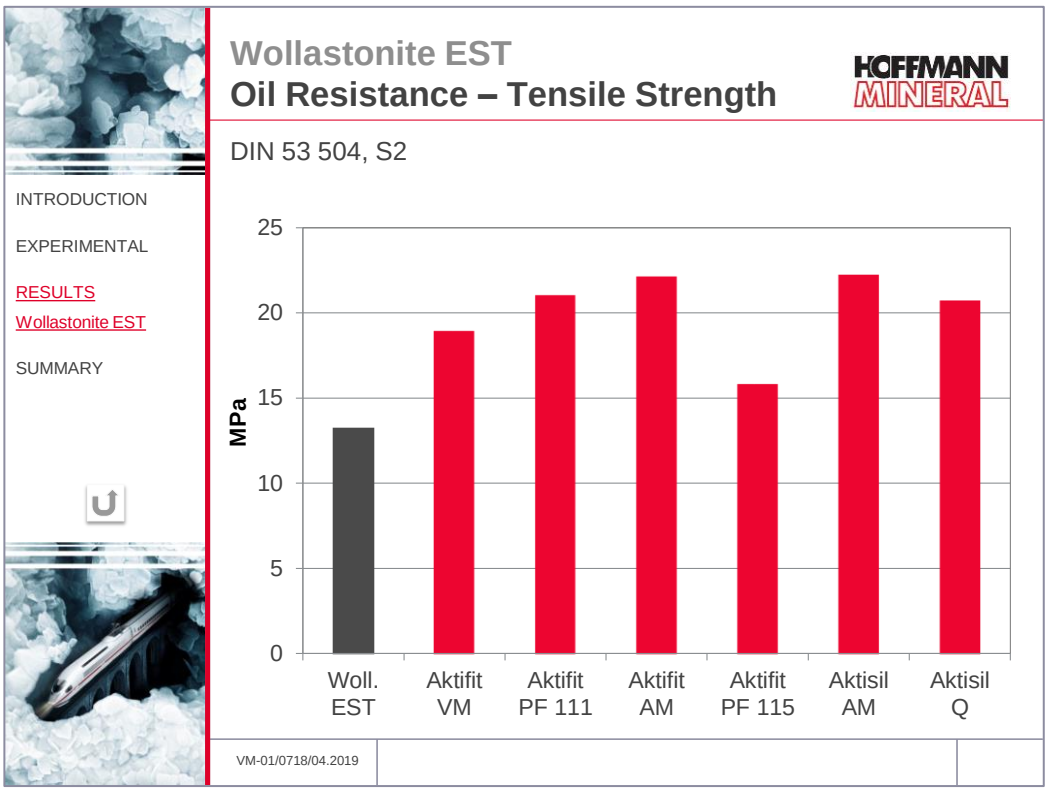

Fig. 27

3.2.3.3 Resistance to acid

Replacing the epoxysilane-treated wollastonite with Neuburg Siliceous Earth makes the vulcanizates resistant to acetic acid. This is verified both by the changes in tensile strength, elongation at break (Fig. 28) and hardness, which is no longer measurable because the test specimen is destroyed during testing (Fig. 29), and by the increase in volume of the test specimen (Fig. 30 + Fig. 31).

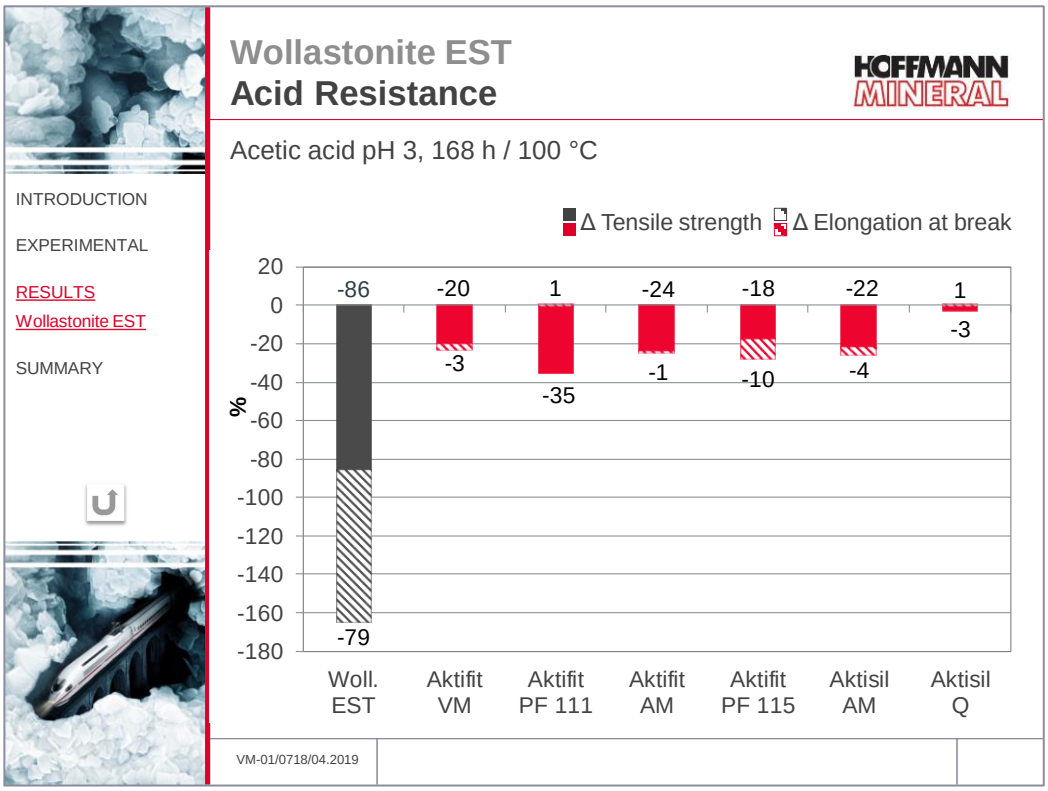
Wollastonite EST
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
Δ Tensile strength
Δ Elongation at break
INTRODUCTION
EXPERIMENTAL
RESULTS
Wollastonite EST
SUMMARY
%
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-86
-79
-20
-3
1
-35
-24
-1
-18
-10
-22
-4
1
-3
Woll. EST
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
VM-01/0718/04.2019

Fig. 28

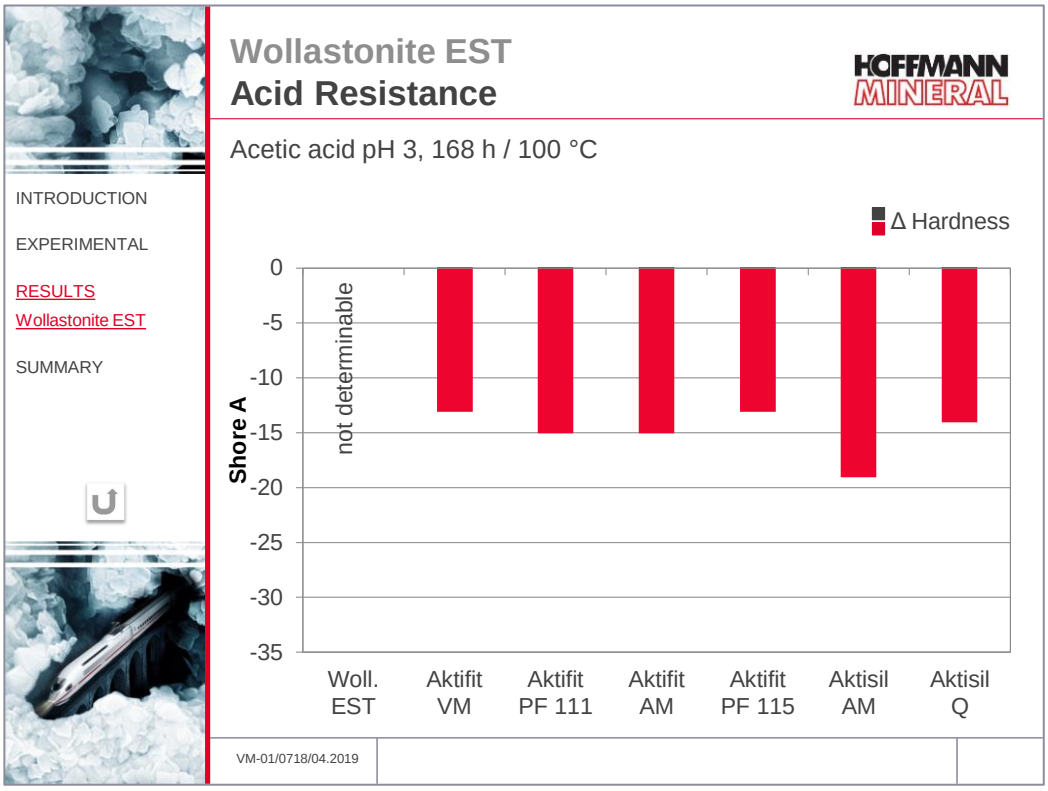
Wollastonite EST
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
Δ Hardness
INTRODUCTION
EXPERIMENTAL
RESULTS
Wollastonite EST
SUMMARY
Shore A
0
-5
-10
-15
-20
-25
-30
-35
not determinable
Woll. EST
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
VM-01/0718/04.2019

Fig. 29

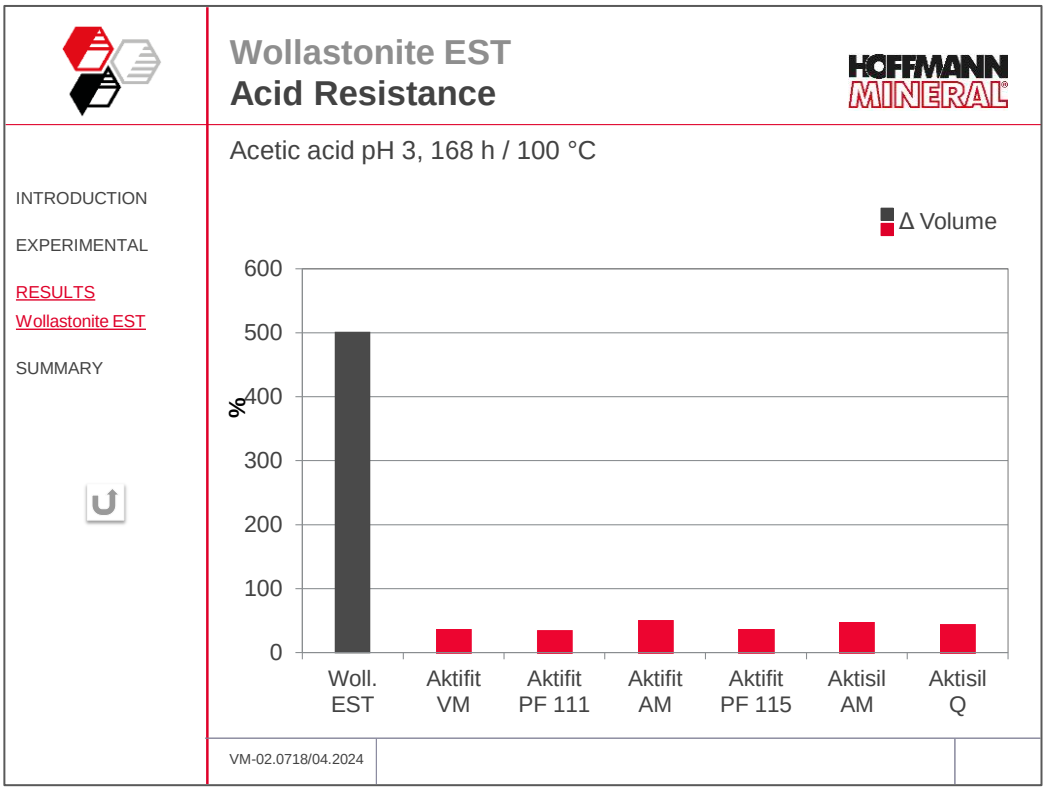
Wollastonite EST
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
INTRODUCTION
EXPERIMENTAL
RESULTS
Wollastonite EST
SUMMARY
Δ Volume
%
600
500
400
300
200
100
0
Woll. EST
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
VM-02.0718/04.2024

Fig. 30


Wollastonite EST
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
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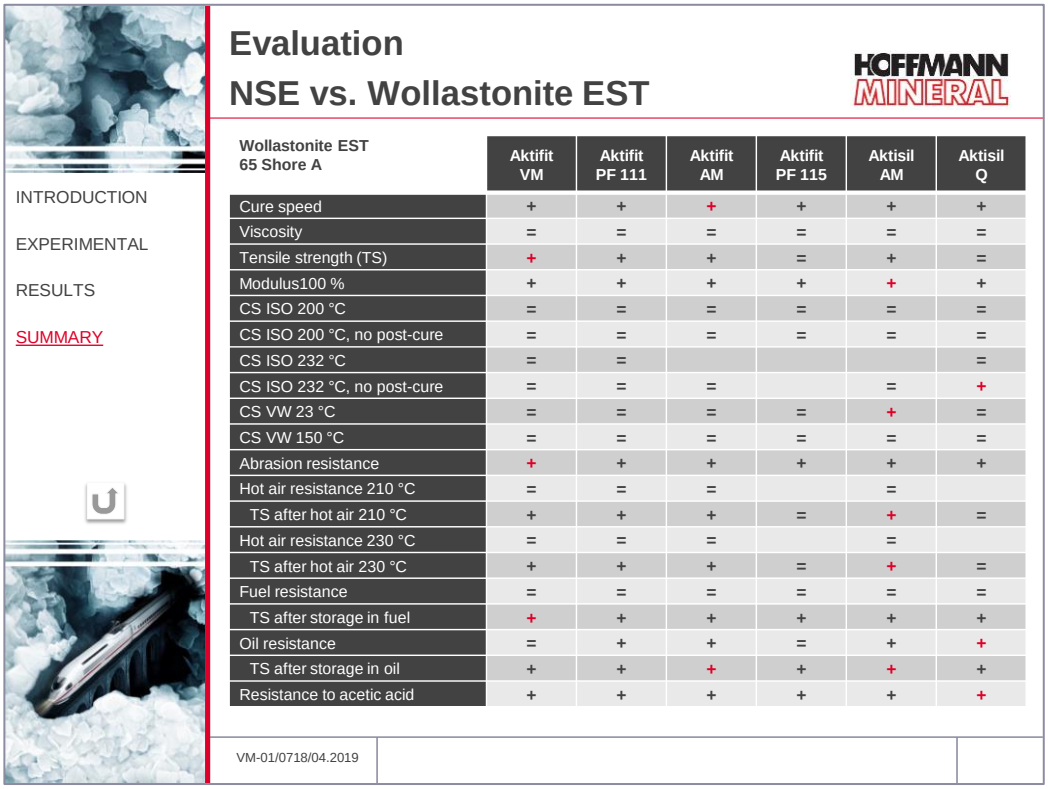
RESULTS
Wollastonite EST
SUMMARY
before
after
Δ weight: +227 %
Δ volume: +500 %
VM-01/0718/04.2019

Fig. 31

3.2.4 Evaluation of the results

Various properties and combinations of properties – often even contradicting properties – are positively influenced by the Neuburg Siliceous Earth products. This is verified in the following summary analysis.



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Evaluation
NSE vs. Wollastonite EST

HOFFMANN MINERAL

Wollastonite EST 65 Shore A	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Cure speed	+	+	+	+	+	+
Viscosity	=	=	=	=	=	=
Tensile strength (TS)	+	+	+	=	+	=
Modulus100 %	+	+	+	+	+	+
CS ISO 200 °C	=	=	=	=	=	=
CS ISO 200 °C, no post-cure	=	=	=	=	=	=
CS ISO 232 °C	=	=				=
CS ISO 232 °C, no post-cure	=	=	=		=	+
CS VW 23 °C	=	=	=	=	+	=
CS VW 150 °C	=	=	=	=	=	=
Abrasion resistance	+	+	+	+	+	+
Hot air resistance 210 °C	=	=	=		=	
TS after hot air 210 °C	+	+	+	=	+	=
Hot air resistance 230 °C	=	=	=		=	
TS after hot air 230 °C	+	+	+	=	+	=
Fuel resistance	=	=	=	=	=	=
TS after storage in fuel	+	+	+	+	+	+
Oil resistance	=	+	+	=	+	+
TS after storage in oil	+	+	+	+	+	+
Resistance to acetic acid	+	+	+	+	+	+

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Fig. 32

Fig. 32 shows which NSE grades either improve (+) or match (=) the relevant property performance versus the aminosilane-treated wollastonite. Red + signs indicate the NSE product that achieves the best result for the appropriate property among NSE grades.

3.3 Neuburg Siliceous Earth versus Barium Sulfate

3.3.1 Rheological properties

Replacing barium sulfate with Silfit Z 91 and the aminosilane-treated grades of Neuburg Siliceous Earth Aktifit AM, Aktifit PF 115 and Aktisil AM results in faster curing (Fig. 33). These grades also tend to reduce viscosity somewhat (Fig. 34). Aktisil Q seems to have a slightly greater impact in this respect.

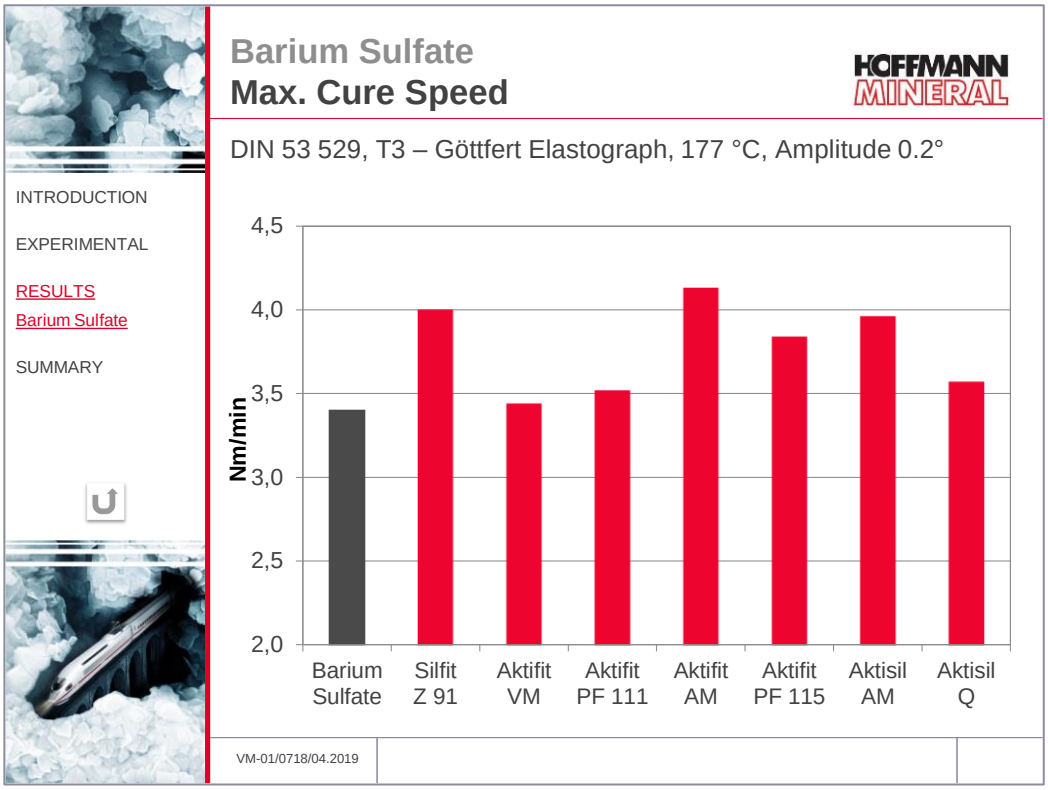


Fig. 33

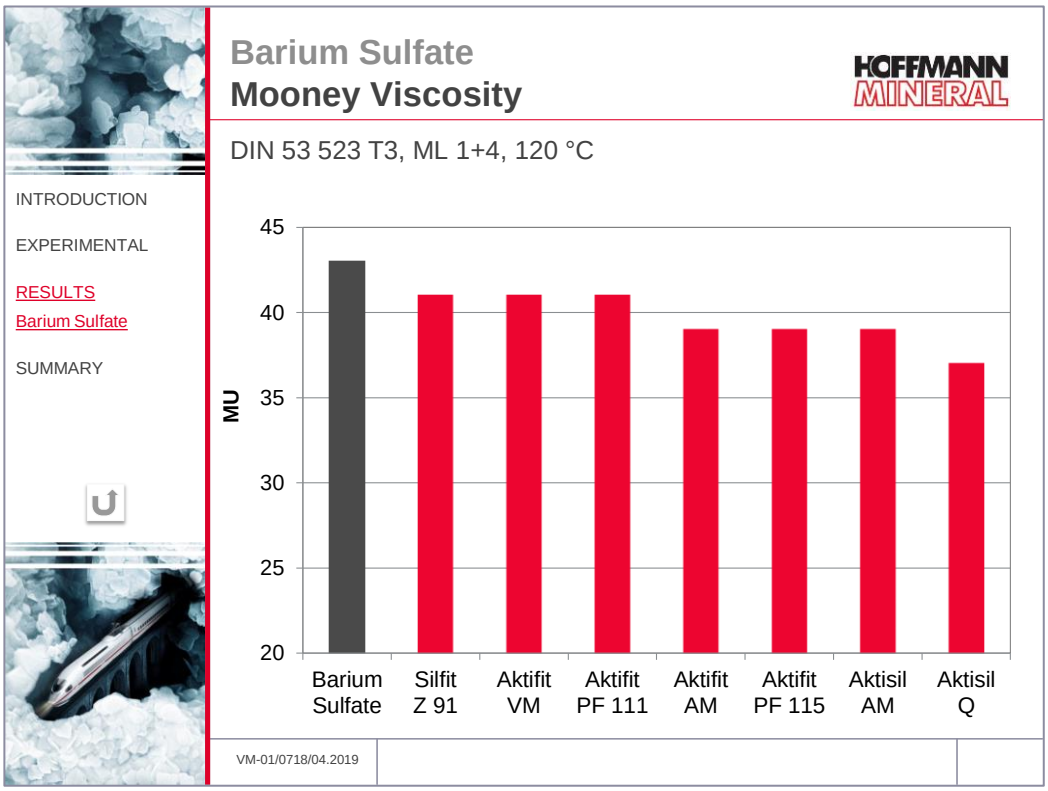


Fig. 34

3.3.2 Mechanical properties

All NSE grades significantly raise tensile strength compared to barium sulfate (Fig. 35). Remarkably, even Silfit Z 91 – a non-functional filler – is able to raise tensile strength by about 5 MPa. Accordingly, Silfit Z 91 can improve tensile strength without compromising elongation at break (Fig. 36). Most of the surface-treated grades of Neuburg Siliceous Earth also demonstrate acceptable elongation at break, however. At the same, they are able to nearly double moduli at 100 % elongation (Fig. 37).
Further, replacing barium sulfate with Silfit Z 91 or Aktifit PF 115 results in comparable tear resistance, as shown in Fig. 38. As far as tensile performance is concerned, therefore, Silfit Z 91, represents an excellent alternative to barium sulfate.

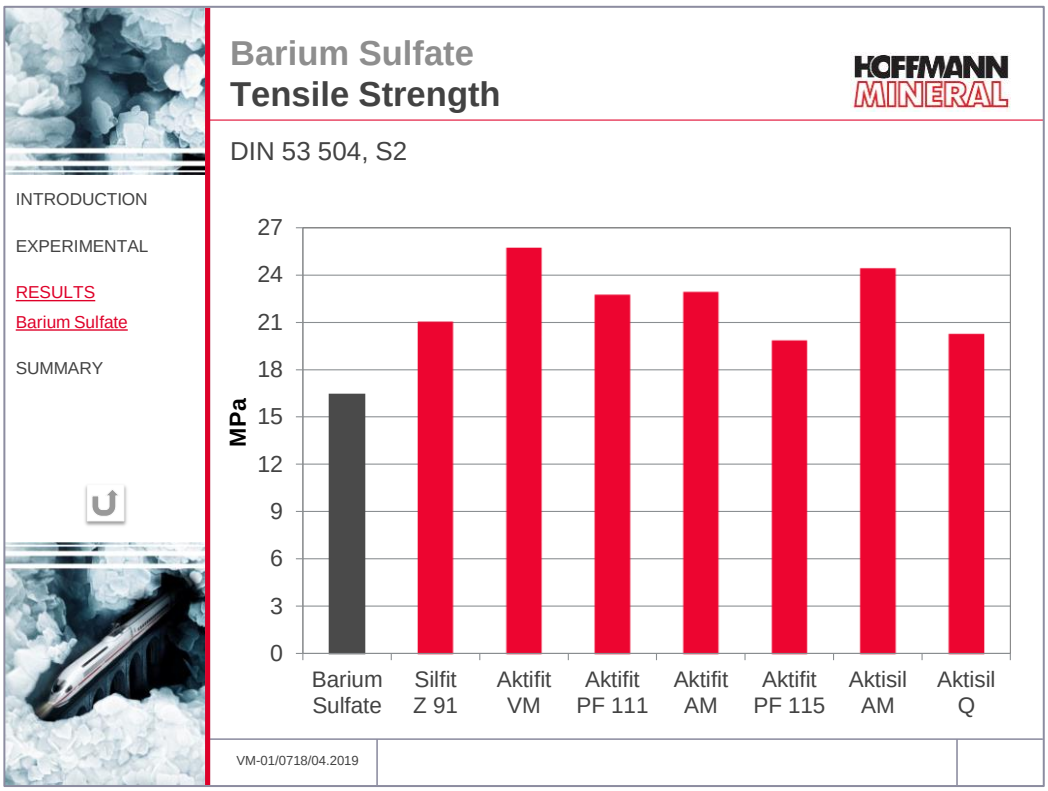
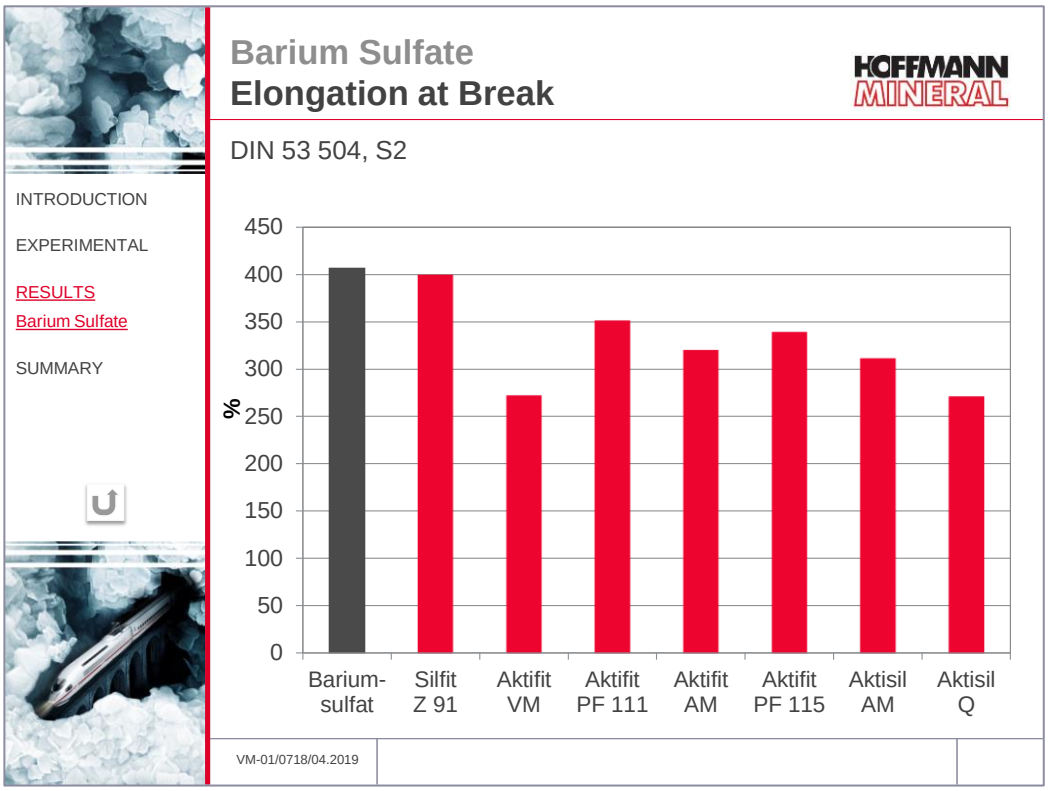


Fig. 35


Barium Sulfate
Elongation at Break
HOFFMANN MINERAL
DIN 53 504, S2
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RESULTS
Barium Sulfate
SUMMARY
%
450
400
350
300
250
200
150
100
50
0
Barium-sulfat
Silfit Z 91
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
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Fig. 36

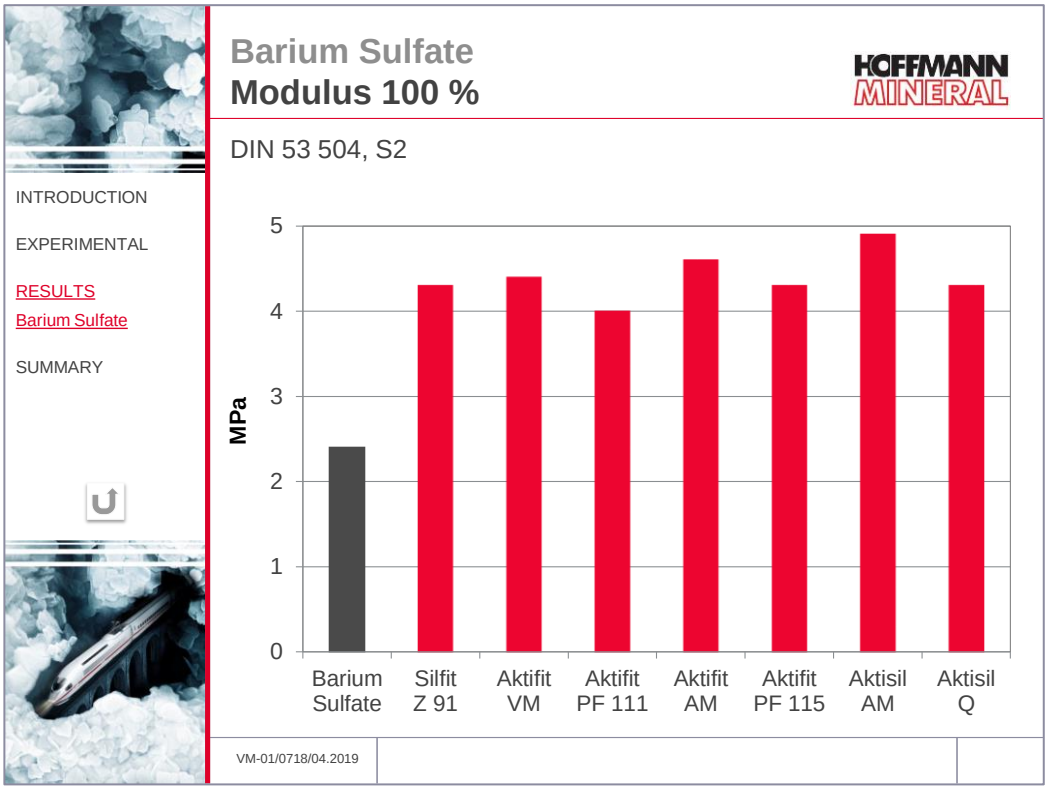
Barium Sulfate
Modulus 100 %
HOFFMANN MINERAL
DIN 53 504, S2
INTRODUCTION
EXPERIMENTAL
RESULTS
Barium Sulfate
SUMMARY
MPa
5
4
3
2
1
0
Barium Sulfate
Silfit Z 91
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
VM-01/0718/04.2019

Fig. 37

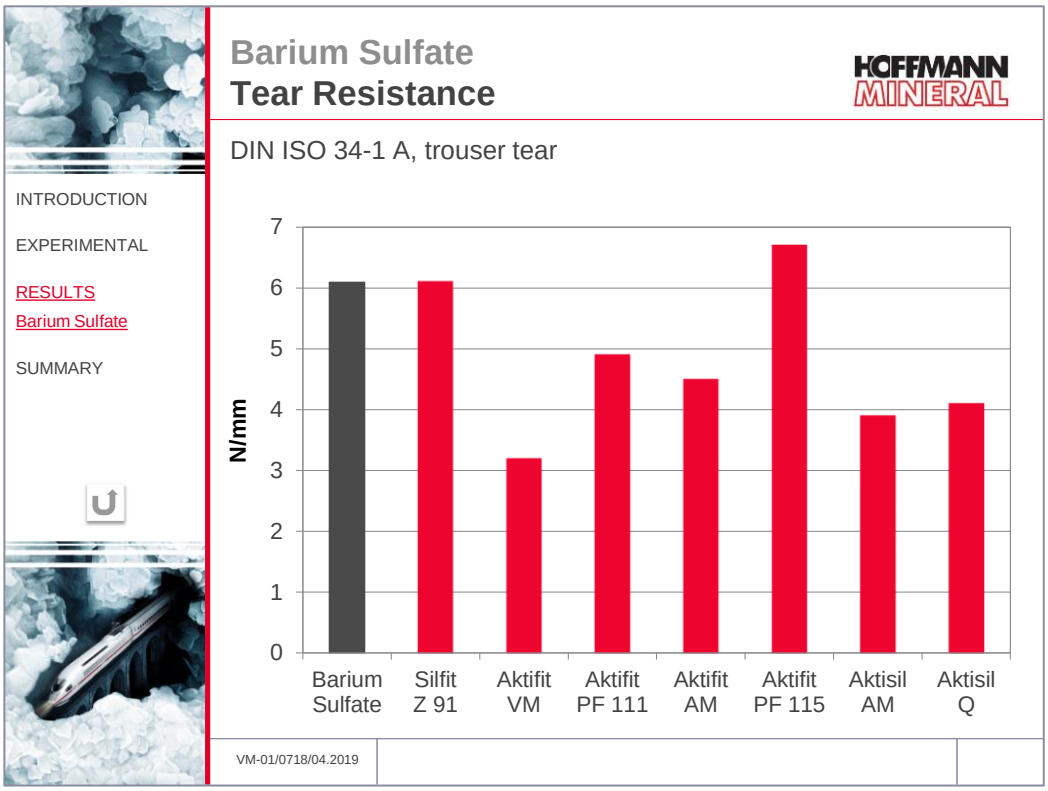

Fig. 38

Replacing the barium sulfate with Neuburg Siliceous Earth results in a reduction of the compression set. Fig. 39 shows the compression set as per DIN ISO 815-1 B after 70 hours at 232 °C. The improvement with Aktifit VM, Aktifit PF 111 and especially Aktisil Q is clearly apparent. Aktisil Q, in particular, offers the benefit of significantly reducing compression set even on test specimens, that have not been post-cured.

If VW's compression set as per PV 3307 is important, the use of Aktisil AM is recommended as it results in the best value at room temperature (Fig. 40).

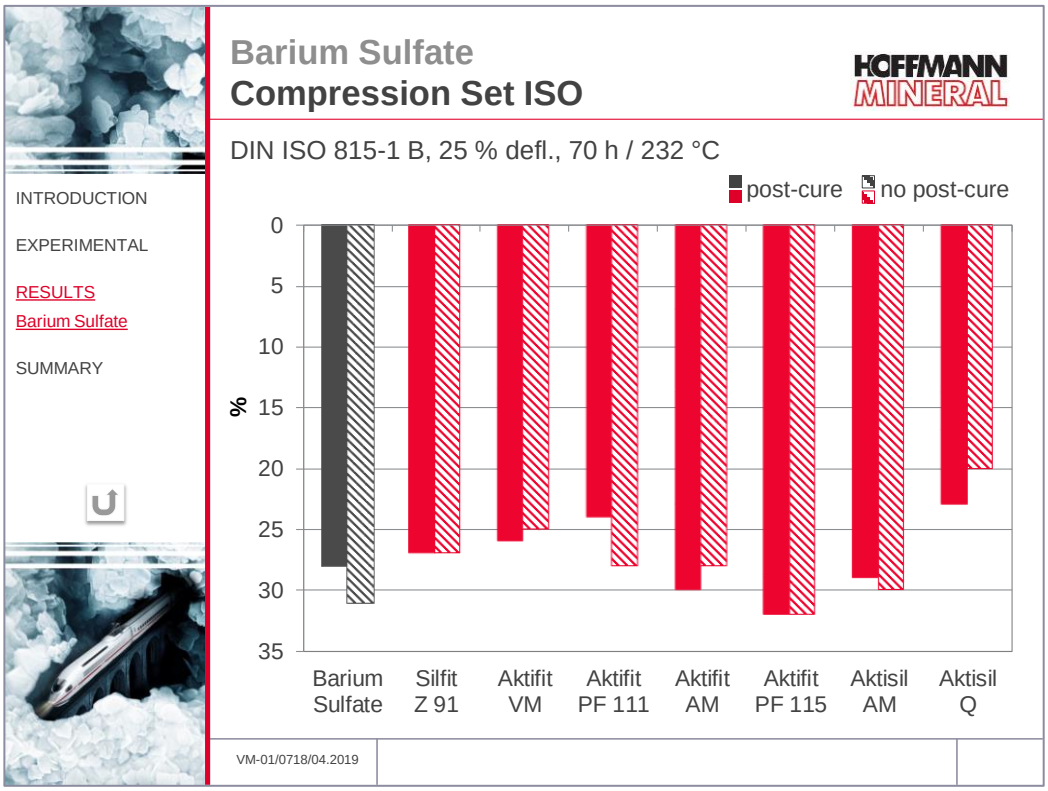

Fig. 39

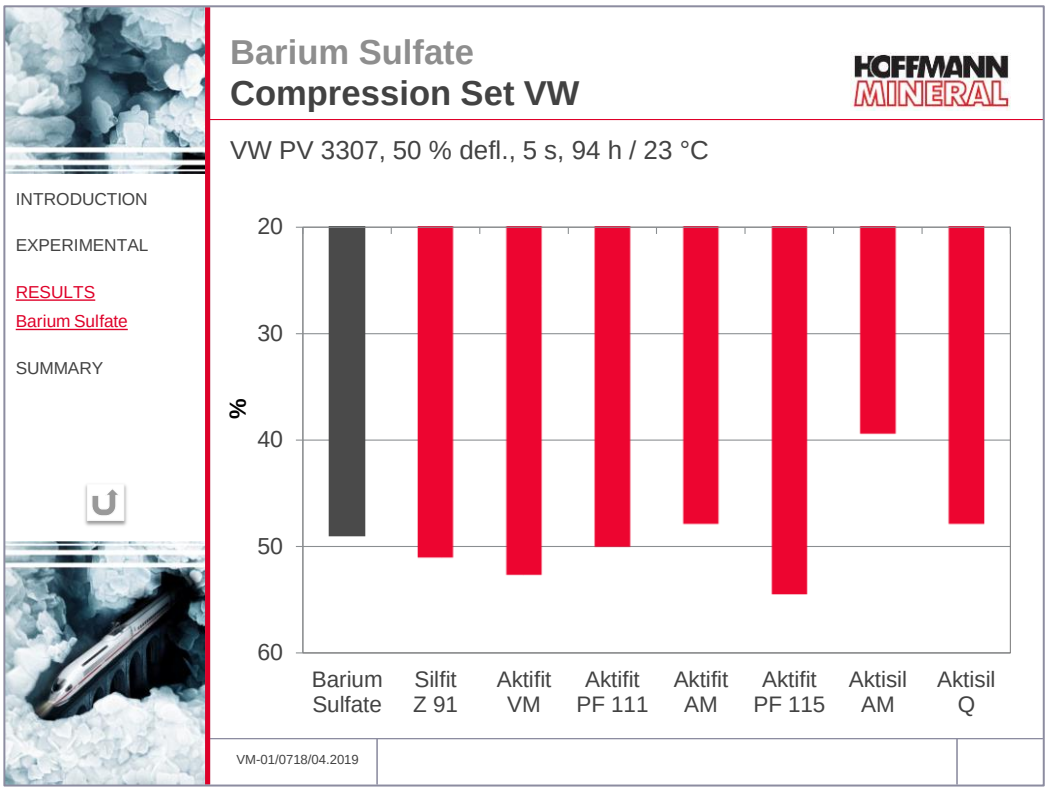

Fig. 40

If applications require improved abrasion resistance, the barium sulfate can be replaced with any of the NSE variants addressed in this paper (Fig. 41).

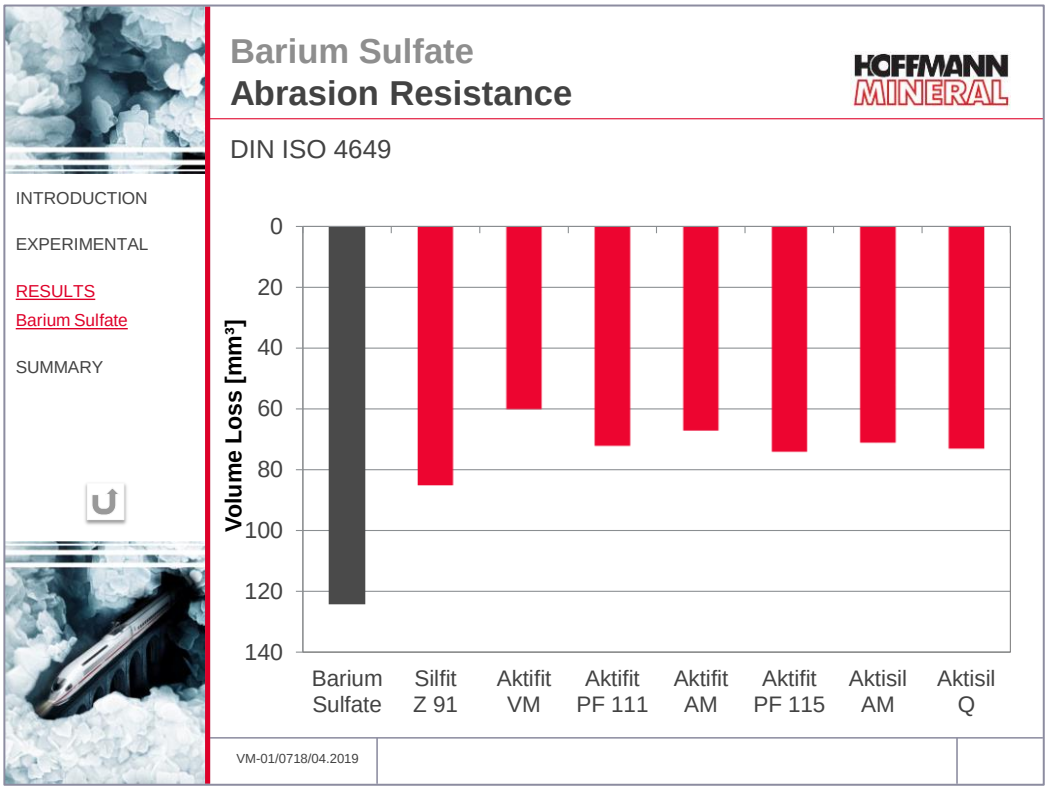

Fig. 41

3.3.3 Media resistance

3.3.3.1 Resistance to hot air

As the changes in tensile strength and elongation at break after aging in hot air show, NSE achieves comparable, and in most cases even better resistance to hot air than barium sulfate (Fig. 42 and Fig. 43).

Aktifit VM is particularly resistant at a short-term aging temperature of 230 °C. If the temperature remains at 210 °C for longer periods, the use of Aktifit PF 111, Aktifit AM or Aktisil AM is recommended.

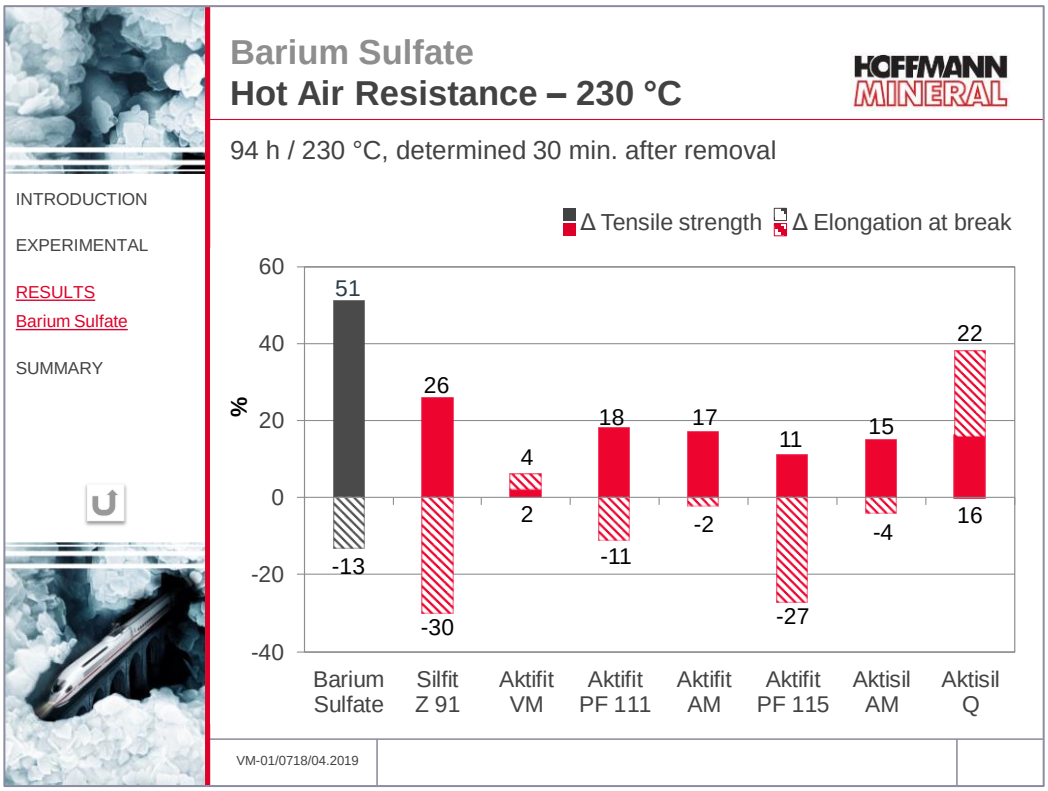

Fig. 42

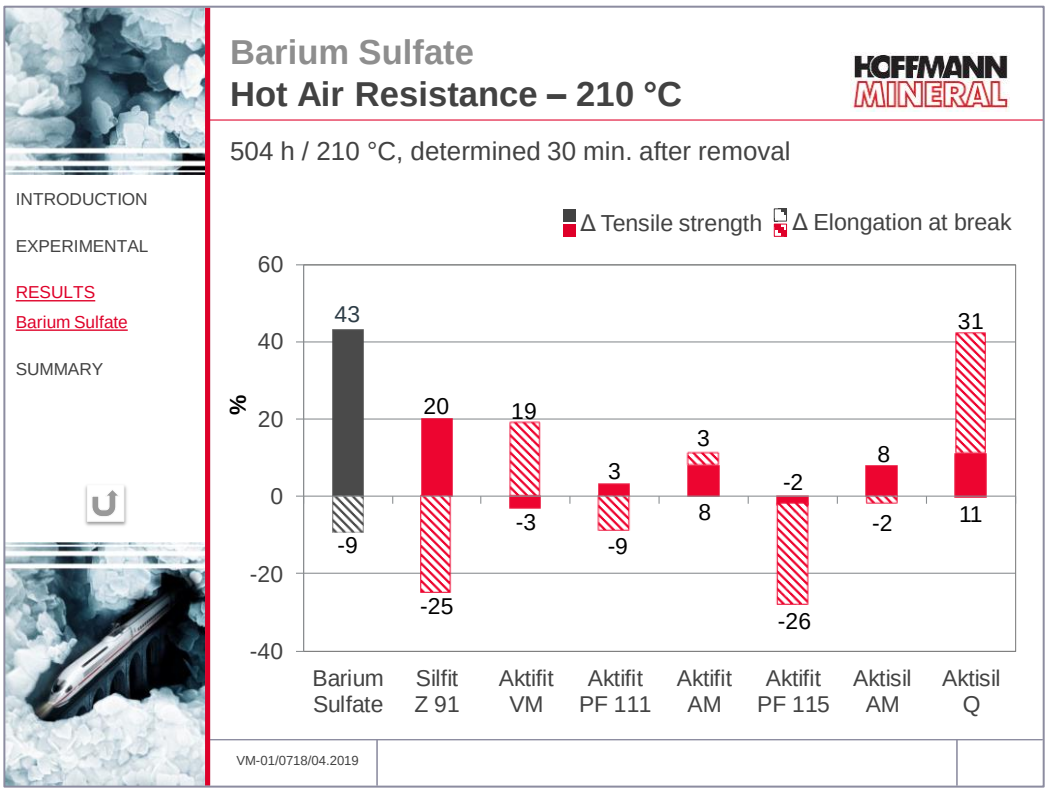

Fig. 43

3.3.3.2 Resistance to fuel

After immersion in fuel, the hardness of the vulcanizate filled with barium sulfate decreases to a greater degree than that of the vulcanizates made with Neuburg Siliceous Earth (Fig. 44).

The changes in tensile strength and elongation at break are comparable. As such, the greater strength of the NSE types is maintained when the vulcanizates were exposed to fuel (Fig. 45).

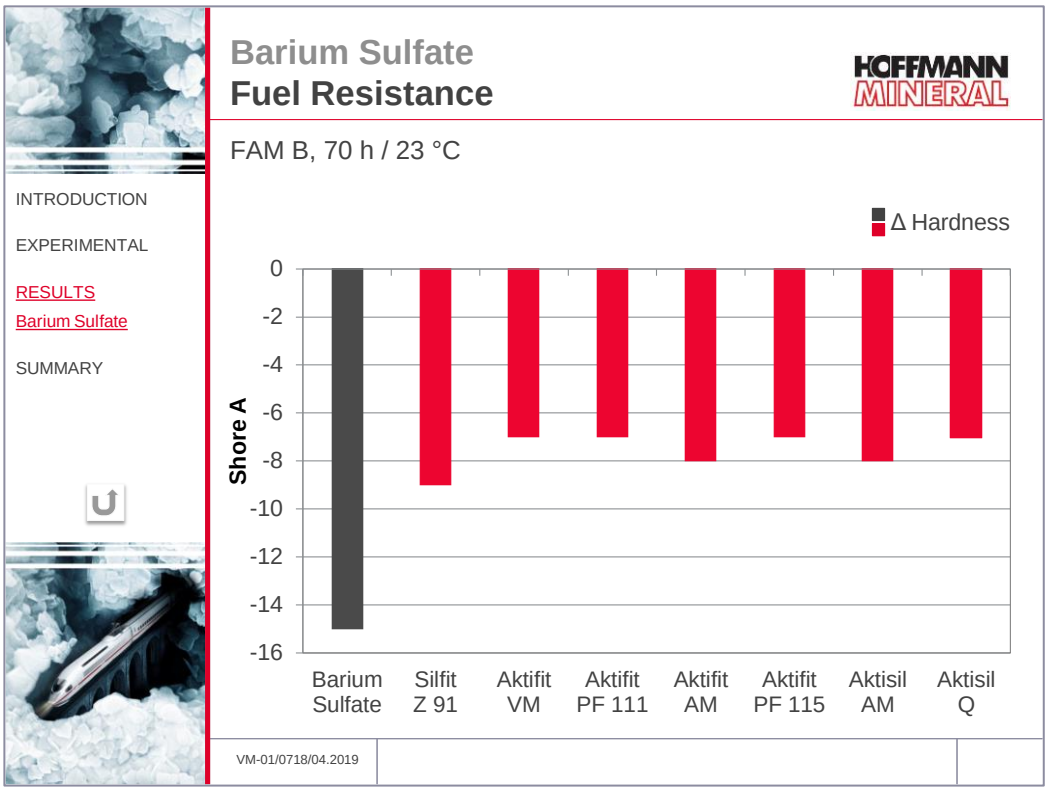

Fig. 44

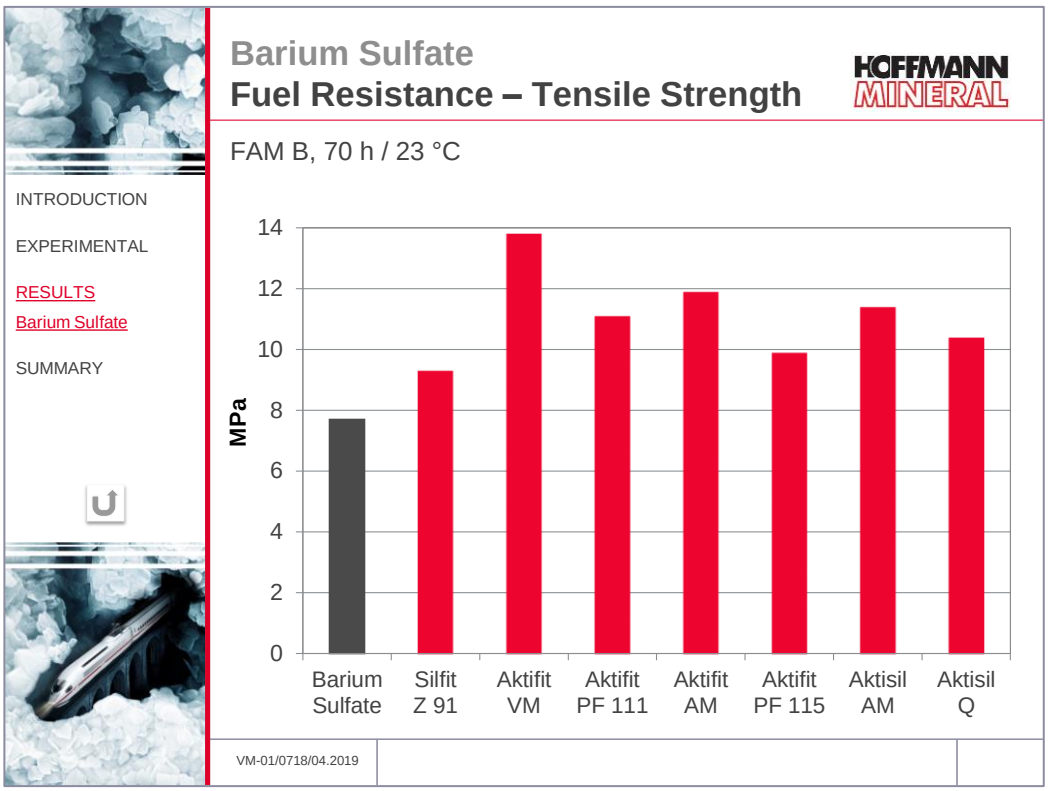

Fig. 45

3.3.3.3 Resistance to oil

Replacing barium sulfate with Neuburg Siliceous Earth results, in most cases, in vulcanizates with lesser changes in tensile strength and elongation at break (Fig. **46**) and in all cases in less loss of hardness (Fig. 48). Thus, hardness and tensile strength performance (Fig. 47) are virtually unchanged. The NSE variants addressed in this paper therefore clearly improve resistance to oil, compared to barium sulfate.

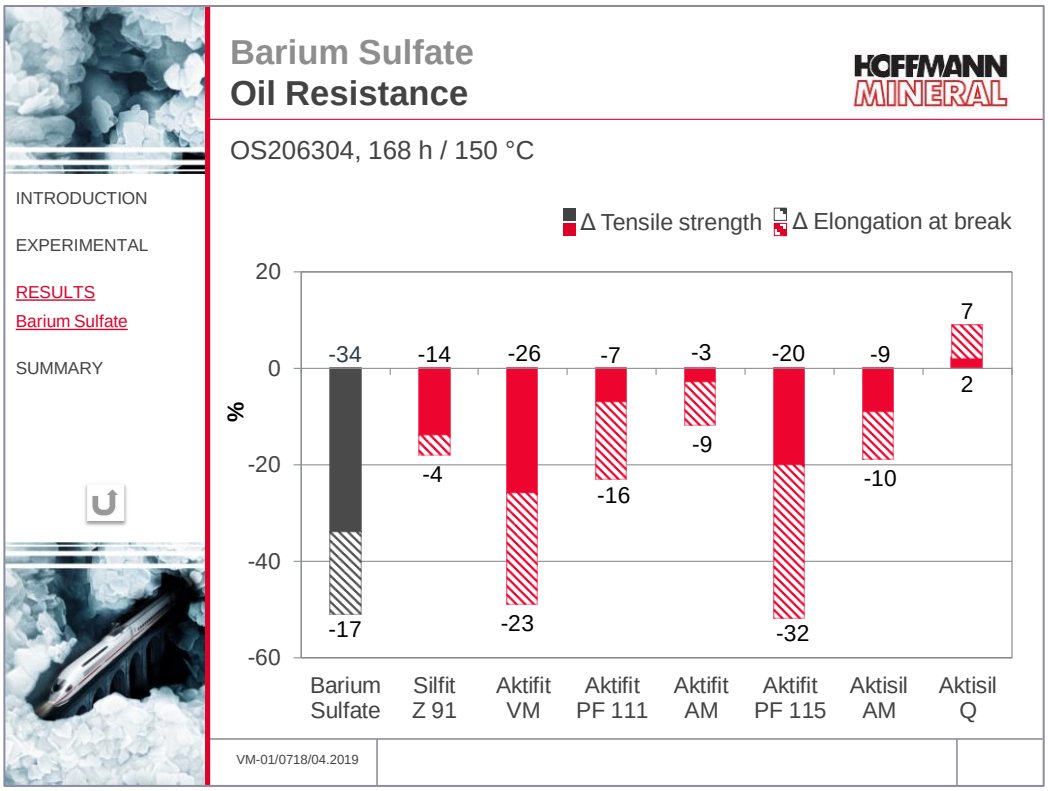

Fig. 46

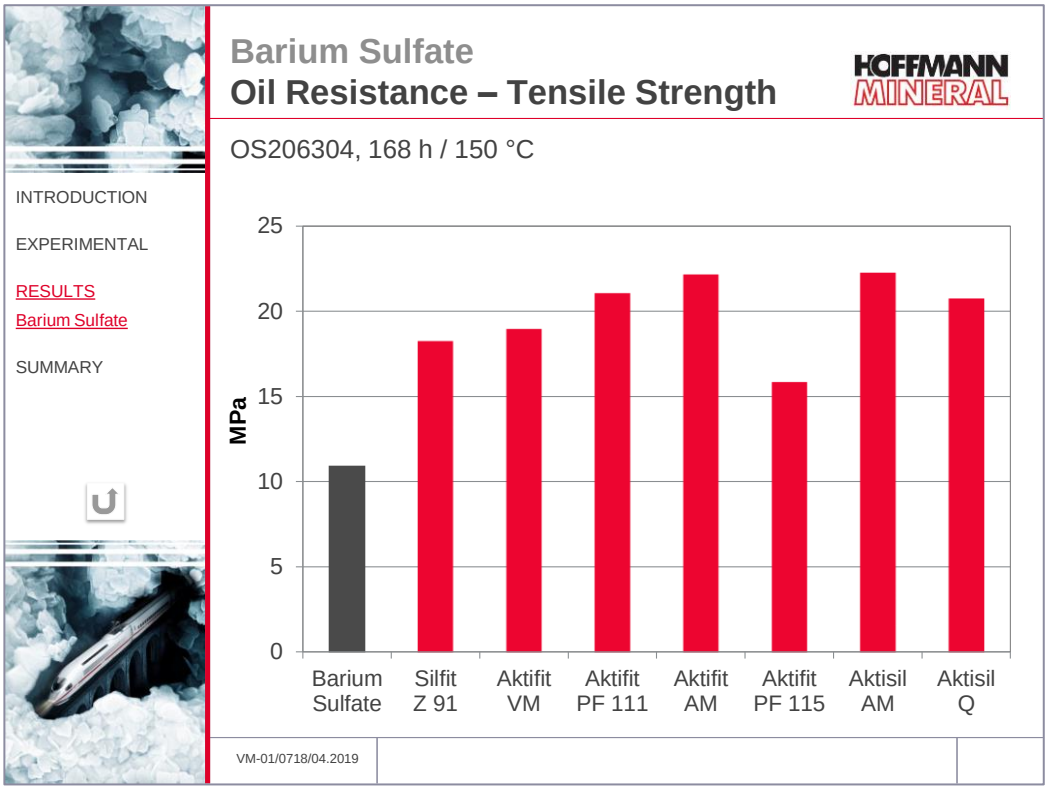

Fig. 47

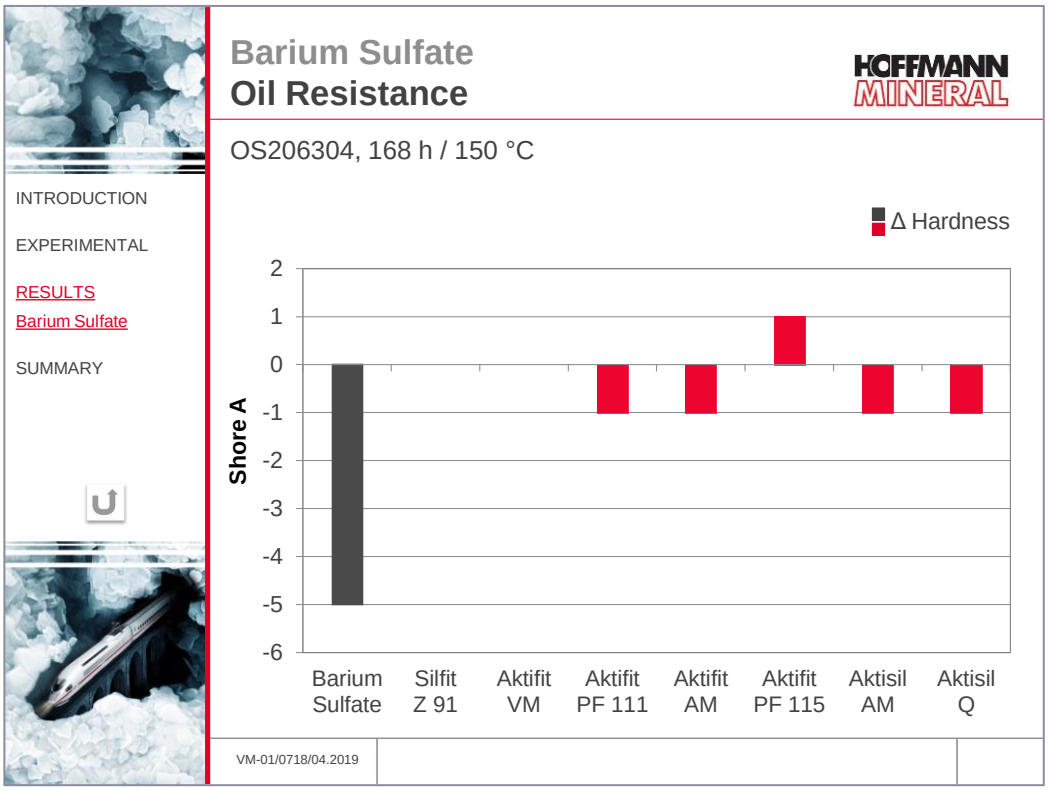

Fig. 48

3.3.3.4 Resistance to acid

Barium sulfate already achieves a significant improvement in resistance to acid versus wollastonite. Neuburg Siliceous Earth is, however, able to further improve the relatively good result achieved with barium sulfate. Especially the silanized NSE variants result in virtually no change in elongation at break (Fig. 49). Generally, Neuburg Siliceous Earth proves to result in less loss of hardness (Fig. 50), and the volume of the test specimens also increases to a much lesser degree than with barium sulfate. Even Silfit Z 91 – which is not surface-treated – manages to achieve a significant improvement (Fig. 51 and Fig. 52).

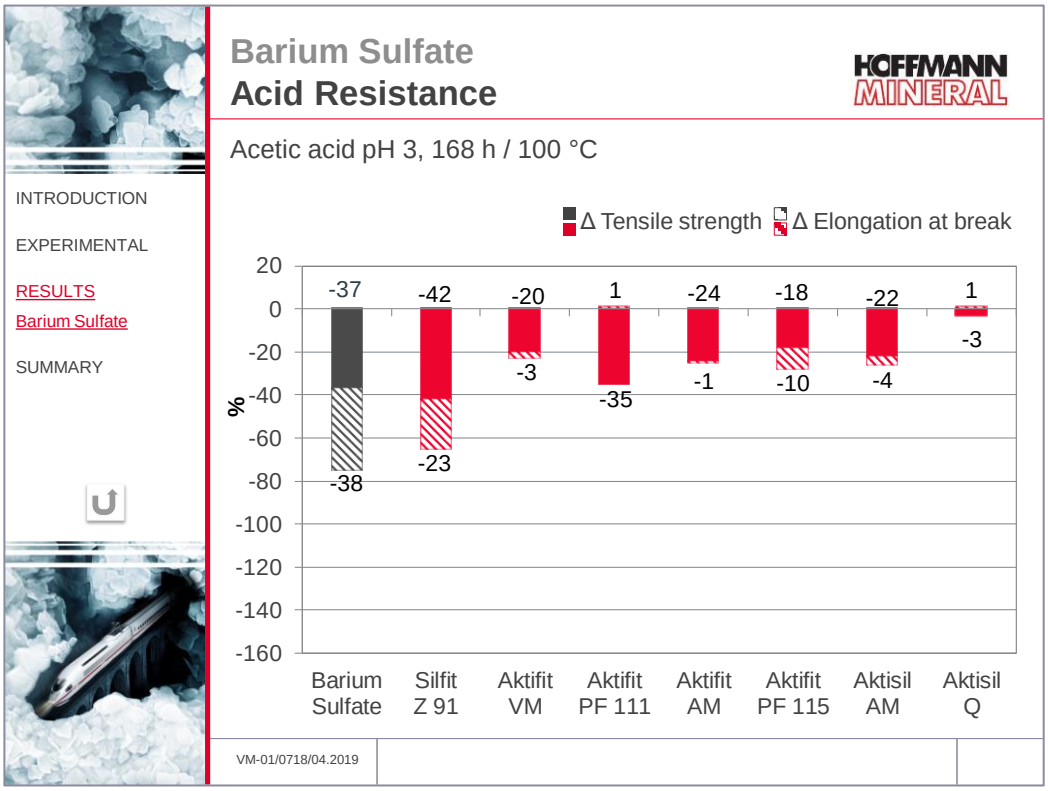

Fig. 49

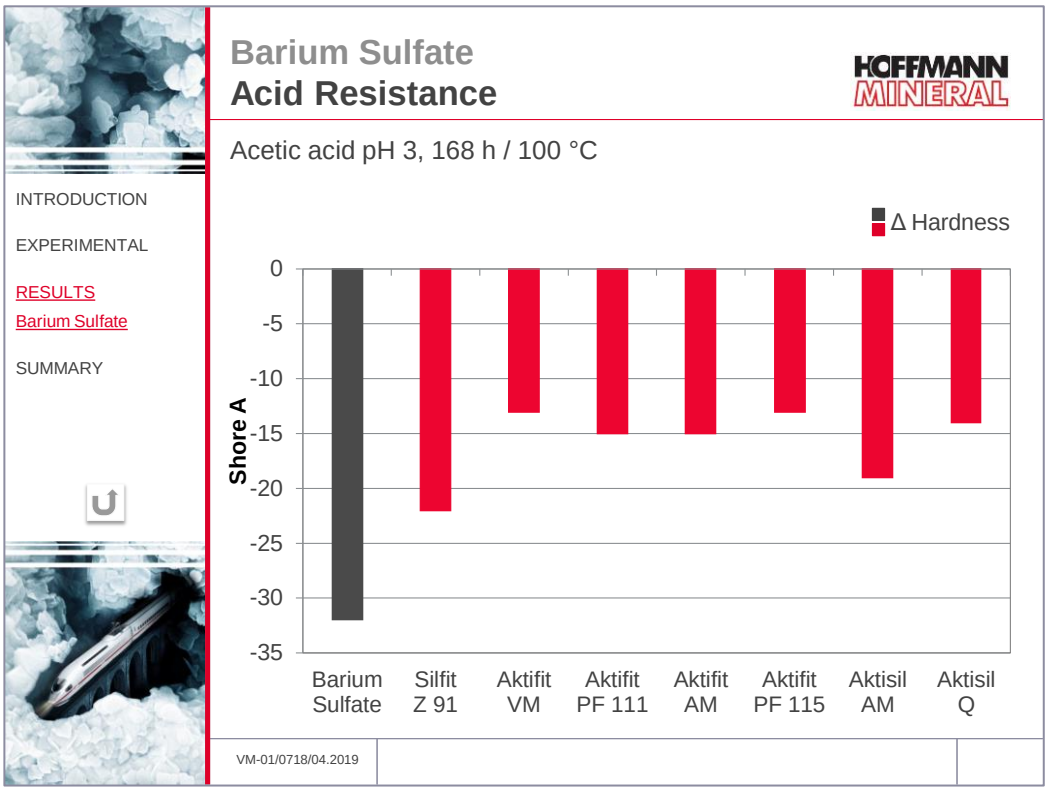
Barium Sulfate
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
Δ Hardness
Shore A
0
-5
-10
-15
-20
-25
-30
-35
Barium Sulfate
Silfit Z 91
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
Aktisil Q
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Fig. 50

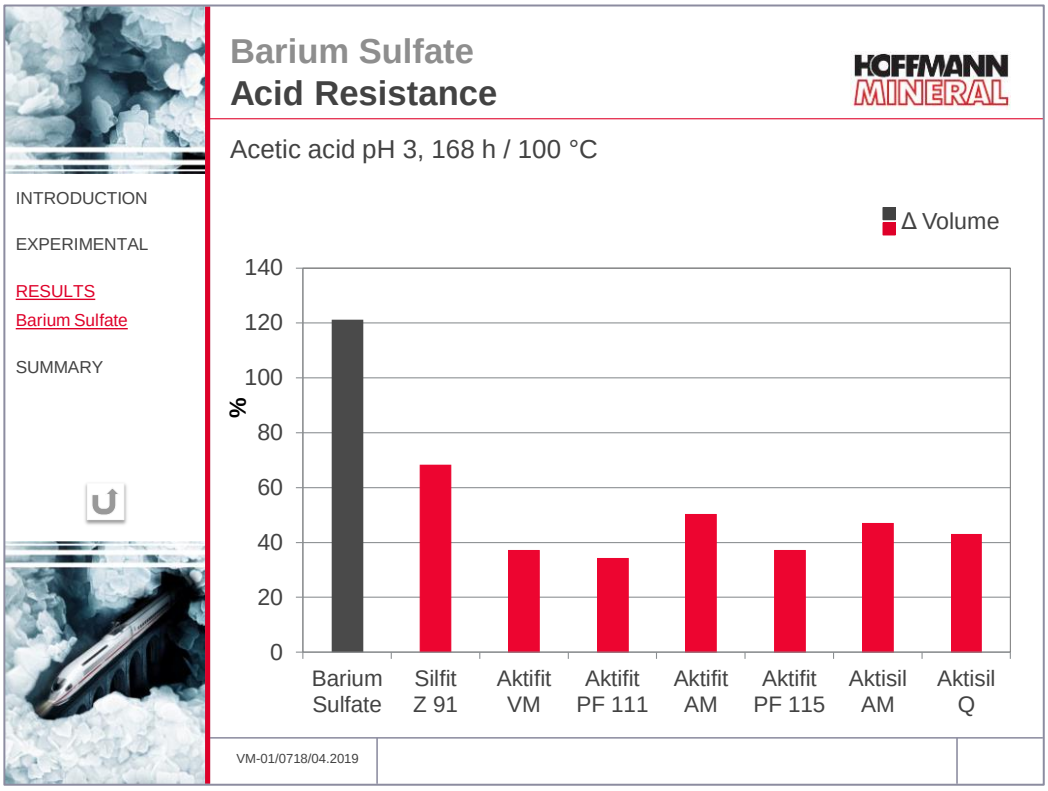
Barium Sulfate
Acid Resistance
HOFFMANN MINERAL
Acetic acid pH 3, 168 h / 100 °C
Δ Volume
%
140
120
100
80
60
40
20
0
Barium Sulfate
Silfit Z 91
Aktifit VM
Aktifit PF 111
Aktifit AM
Aktifit PF 115
Aktisil AM
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Fig. 51

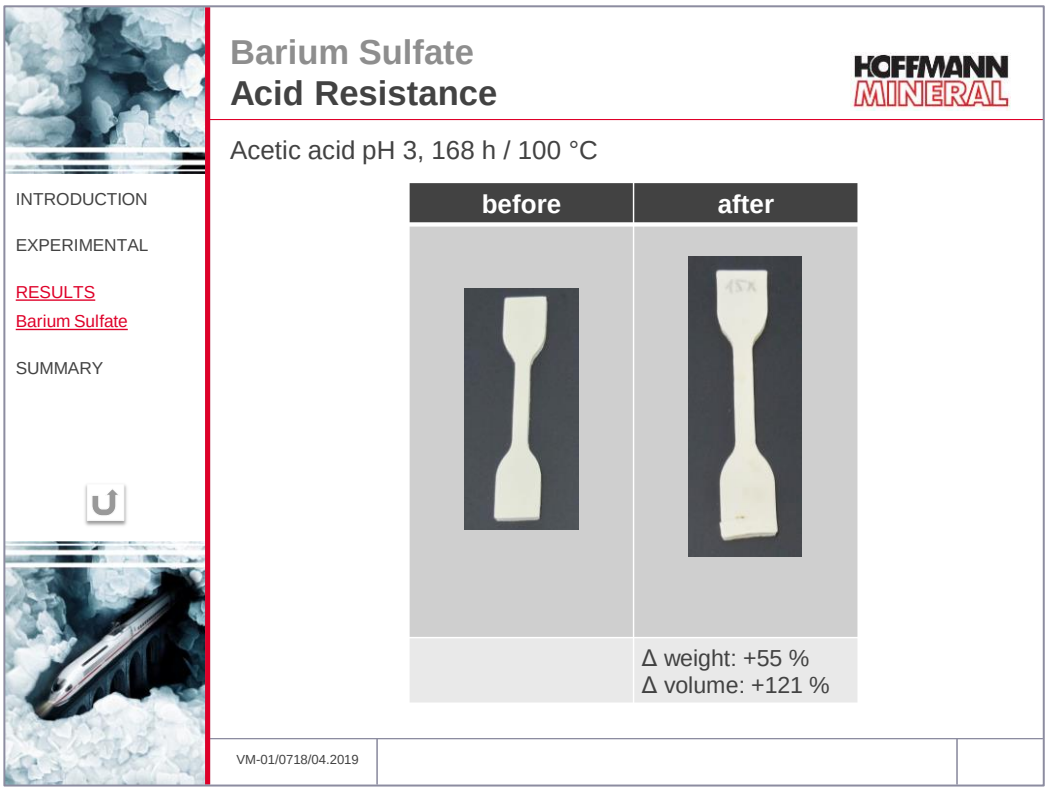
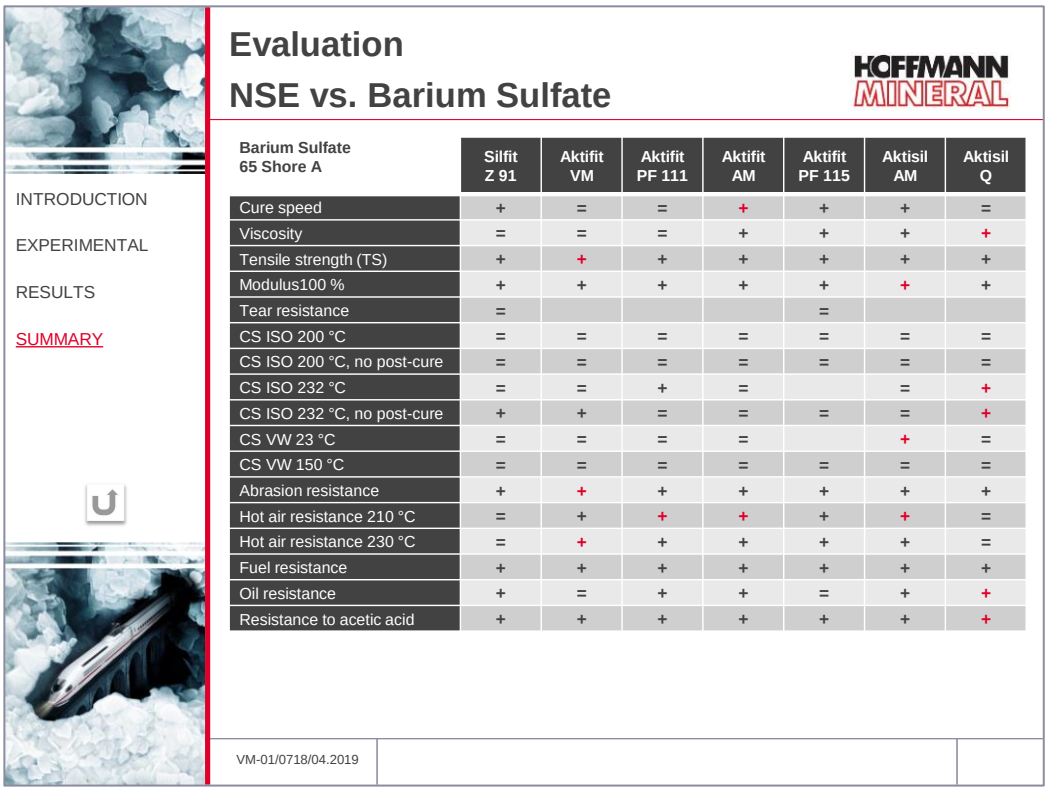


Fig. 52

3.3.4 Evaluation of the results

Various properties and combinations of properties – often even contradicting properties – are positively influenced by the Neuburg Siliceous Earth products. This is verified in the following summary analysis.



Barium Sulfate 65 Shore A	Silfit Z 91	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Cure speed	+	=	=	+	+	+	=
Viscosity	=	=	=	+	+	+	+
Tensile strength (TS)	+	+	+	+	+	+	+
Modulus100 %	+	+	+	+	+	+	+
Tear resistance	=				=		
CS ISO 200 °C	=	=	=	=	=	=	=
CS ISO 200 °C, no post-cure	=	=	=	=	=	=	=
CS ISO 232 °C	=	=	+	=		=	+
CS ISO 232 °C, no post-cure	+	+	=	=	=	=	+
CS VW 23 °C	=	=	=	=		+	=
CS VW 150 °C	=	=	=	=	=	=	=
Abrasion resistance	+	+	+	+	+	+	+
Hot air resistance 210 °C	=	+	+	+	+	+	=
Hot air resistance 230 °C	=	+	+	+	+	+	=
Fuel resistance	+	+	+	+	+	+	+
Oil resistance	+	=	+	+	=	+	+
Resistance to acetic acid	+	+	+	+	+	+	+

Fig. 53

Fig. 53 shows which NSE grades either improve (+) or match (=) the relevant property performance versus the barium sulfate. Red + signs indicate the NSE product that achieves the best result for the appropriate property among NSE grades.

4 Summary

Several NSE grades raise cure speed compared to wollastonite or barium sulfate. By shortening the heating times, production costs could therefore be saved.

The somewhat lower viscosity resulting from replacing barium sulfate could indicate better flow properties in injection moulding (this would, however, require validation in tests of the appropriate shear rates).

Generally, the Neuburg Siliceous Earth grades addressed in this paper produce better tensile strength performance than wollastonite or barium sulfate and improve abrasion resistance.

Resistance to hot air, oil or fuel can also be increased by using Neuburg Siliceous Earth instead of wollastonite or barium sulfate.

One particular advantage of this replacement is the significantly improved resistance of the vulcanizates filled with NSE to acetic acid, which can be used to simulate blow-by resistance. Thus, the possible applications of light-colored vulcanizates are significantly increased.

Neuburg Siliceous Earth therefore represents an alternative to wollastonite and barium sulfate in peroxide-cured FKM that can be used to generate various – improved – property profiles.

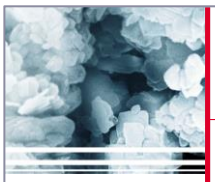


Table of Results

HOFFMANN MINERAL

Loading 30 phr		Silfit Z 91	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Rheology								
Mooney Viscosity, ML Min., 120 °C	MU	41	41	41	39	39	39	37
Rotorless Curemeter M_{min} 177 °C	Nm	0.05	0.04	0.04	0.04	0.05	0.04	0.04
Rotorless Curemeter V_{max} 177 °C	Nm/min.	4.0	3.4	3.5	4.1	3.8	4.0	3.6
Rotorless Curemeter t_{90} 177 °C	min.	0.8	0.8	0.9	0.8	0.8	0.8	0.8
Mechanical Properties – Cure Conditions 7 min. / 177 °C, no post-cure								
Hardness	Sh. A	65	64	65	65	65	64	63
Tensile Strength	MPa	15	22	16	18	17	19	16
Modulus 50 %	MPa	1.74	1.70	1.68	1.68	1.72	1.83	1.60
Modulus 100 %	MPa	3.2	3.9	3.5	3.7	3.6	4.2	3.6
Elongation at Break	%	405	278	336	364	395	312	257
Tear Resistance	N/mm	6.2	3.1	5.4	4.7	6.0	4.5	4.0
CS ISO, 70 h / 200 °C, 25 % defl.	%	19	20	21	20	21	21	18
CS ISO 70 h / 232 °C, 25 % defl.	%	27	25	28	28	32	30	20

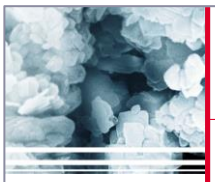
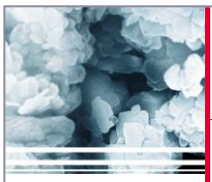


Table of Results

HOFFMANN MINERAL

Loading 30 phr		Silfit Z 91	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Mechanical Properties – Cure Conditions 7 min. / 177 °C, Post-cure 2 h / 232 °C								
Hardness	Sh. A	66	65	66	66	65	66	65
Tensile Strength	MPa	21	26	23	23	20	24	20
Modulus 50 %	MPa	1.91	1.75	1.76	1.83	1.84	1.92	1.72
Modulus 100 %	MPa	4.3	4.4	4.0	4.6	4.3	4.9	4.3
Elongation at Break	%	399	272	351	320	339	311	271
Tear Resistance	N/mm	6.1	3.2	4.9	4.5	6.7	3.9	4.1
CS ISO, 70 h / 200 °C, 25 % def.	%	21	21	19	20	20	21	20
CS ISO 70 h / 232 °C, 25 % def.	%	27	26	24	30	32	29	23
CS VW PV3307 94 h / 23 °C, 50 % def.	%	51	53	50	48	54	39	48
CS VW PV3307 94 h / 150 °C, 50 % def.	%	37	37	36	38	39	34	38
Abrasion Loss	mm³	85	60	72	67	74	71	73



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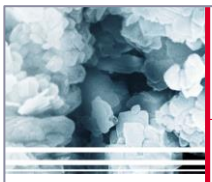
Loading 30 phr		Silfit Z 91	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Hot Air Aging, 504 h / 210 °C, determined after 30 min. after removal								
Hardness	Sh. A	69	68	68	68	69	69	67
Tensile Strength	MPa	25	25	23	25	19	26	22
Elongation at Break	%	301	323	320	330	252	304	356
Δ Hardness	Sh. A	+3	+3	+2	+2	+4	+3	+2
Δ Tensile Strength	%	+20	-3	+3	+8	-2	+8	+11
Δ Elongation at Break	rel.%	-25	+19	-9	+3	-26	-2	+31
Hot Air Aging, 94 h / 230 °C, determined after 30 min. after removal								
Hardness	Sh. A	67	67	68	67	68	68	65
Tensile Strength	MPa	26	26	27	27	22	28	23
Elongation at Break	%	280	283	313	314	247	299	331
Δ Hardness	Sh. A	+1	+2	+2	+1	+3	+2	0
Δ Tensile Strength	%	+26	+2	+18	+17	+11	+15	+16
Δ Elongation at Break	rel.%	-30	+4	-11	-2	-27	-4	+22

VM-01/0718/04.2019



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Loading 30 phr		Silfit Z 91	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Storage in Fuel FAM B, 70 h / 23 °C								
Hardness	Sh. A	57	58	59	58	58	58	58
Tensile Strength	MPa	9.3	14	11	12	9.9	11	10
Elongation at Break	%	335	220	255	246	268	238	206
Δ Hardness	Sh. A	-9	-7	-7	-8	-7	-8	-7
Δ Tensile Strength	%	-56	-46	-51	-48	-50	-53	-49
Δ Elongation at Break	rel.%	-16	-19	-27	-23	-21	-24	-24
Δ Weight	%	+7.9	+7.3	+7.8	+8.0	+8.0	+6.8	+8.0
Δ Volume	%	+19	+18	+19	+19	+19	+17	+19
Storage in Engine Oil OS206304, 168 h / 150 °C								
Hardness	Sh. A	66	65	65	65	66	65	64
Tensile Strength	MPa	18	19	21	22	16	22	21
Elongation at Break	%	383	210	295	291	231	281	291
Δ Hardness	Sh. A	0	0	-1	-1	+1	-1	-1
Δ Tensile Strength	%	-14	-26	-7	-3	-20	-9	+2
Δ Elongation at Break	rel.%	-4	-23	-16	-9	-32	-10	+7
Δ Weight	%	+0.6	+0.8	+0.7	+0.6	+0.6	+0.7	+0.6
Δ Volume	%	+1.0	+1.4	+1.2	+0.9	+1.4	+1.2	+0.7

VM-01/0718/04.2019

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HOFFMANN MINERAL

Loading 30 phr		Silfit Z 91	Aktifit VM	Aktifit PF 111	Aktifit AM	Aktifit PF 115	Aktisil AM	Aktisil Q
Storage in Acetic Acid pH3, 168 h / 100 °C								
Hardness	Sh. A	44	52	51	51	52	47	51
Tensile Strength	MPa	12	21	15	18	16	19	20
Elongation at Break	%	306	265	355	316	304	300	274
Δ Hardness	Sh. A	-22	-13	-15	-15	-13	-19	-14
Δ Tensile Strength	%	-42	-20	-35	-24	-18	-22	-3
Δ Elongation at Break	rel.%	-23	-3	+1	-1	-10	-4	+1
Δ Weight	%	+36	+20	+17	+26	+19	+24	+23
Δ Volume	%	+68	+37	+34	+50	+37	+47	+43

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HOFFMANN MINERAL

		30 phr Wollastonite AST	30 phr Wollastonite EST	49 phr Barium Sulfate
Rheology				
Mooney Viscosity, ML Min., 120 °C	MU	39	37	43
Rotorless Curemeter M_{min} 177 °C	Nm	0.03	0.03	0.04
Rotorless Curemeter V_{max} 177 °C	Nm/min.	3.4	3.1	3.4
Rotorless Curemeter t_{90} 177 °C	min.	0.9	0.9	0.9
Mechanical Properties – Cure Conditions 7 min. / 177 °C, no post-cure				
Hardness	Sh. A	61	63	61
Tensile Strength	MPa	18	16	15
Modulus 50 %	MPa	1.88	1.64	1.44
Modulus 100 %	MPa	4.2	3.2	2.1
Elongation at Break	%	397	393	421
Tear Resistance	N/mm	6.0	5.9	4.7
CS ISO, 70 h / 200 °C, 25 % def.	%	24	21	22
CS ISO 70 h / 232 °C, 25 % def.	%	35	28	31

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HOFFMANN MINERAL

		30 phr Wollastonite AST	30 phr Wollastonite EST	49 phr Barium Sulfate
Mechanical Properties – Cure Conditions 7 min. / 177 °C, Post-cure 2 h / 232 °C				
Hardness	Sh. A	67	64	67
Tensile Strength	MPa	19	20	16
Modulus 50 %	MPa	1.71	1.67	1.44
Modulus 100 %	MPa	3.9	3.5	2.4
Elongation at Break	%	337	399	407
Tear Resistance	N/mm	6.2	6.9	6.1
CS ISO, 70 h / 200 °C, 25 % def.	%	22	18	22
CS ISO 70 h / 232 °C, 25 % def.	%	29	24	28
CS VW PV3307 94 h / 23 °C, 50 % Ddf.	%	51	51	49
CS VW PV3307 94 h / 150 °C, 50 % def.	%	35	36	36
Abrasion Loss	mm³	104	114	124

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HOFFMANN MINERAL

		30 phr Wollastonite AST	30 phr Wollastonite EST	49 phr Barium Sulfate
Hot Air Aging, 504 h / 210 °C, determined after 30 min. after removal				
Hardness	Sh. A	64	64	65
Tensile Strength	MPa	20	21	24
Elongation at Break	%	331	390	372
Δ Hardness	Sh. A	-3	0	-2
Δ Tensile Strength	%	+6	+3	+43
Δ Elongation at Break	rel.%	-2	-2	-9
Hot Air Aging, 94 h / 230 °C, determined after 30 min. after removal				
Hardness	Sh. A	65	65	65
Tensile Strength	MPa	22	22	25
Elongation at Break	%	325	335	353
Δ Hardness	Sh. A	-2	+1	-2
Δ Tensile Strength	%	+18	+8	+51
Δ Elongation at Break	rel.%	-4	-16	-13

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HOFFMANN MINERAL

		30 phr Wollastonite AST	30 phr Wollastonite EST	49 phr Barium Sulfate
Storage in FAM B, 70 h / 23 °C				
Hardness	Sh. A	56	55	52
Tensile Strength	MPa	8.6	7.0	7.7
Elongation at Break	%	241	261	329
Δ Hardness	Sh. A	-11	-9	-15
Δ Tensile Strength	%	-53	-66	-53
Δ Elongation at Break	rel.%	-28	-35	-19
Δ Weight	%	+7.6	+7.2	+7.4
Δ Volume	%	+19	+18	+20
Storage in Engine Oil OS206304, 168 h / 150 °C				
Hardness	Sh. A	62	62	62
Tensile Strength	MPa	17	13	11
Elongation at Break	%	286	297	340
Δ Hardness	Sh. A	-5	-2	-5
Δ Tensile Strength	%	-7	-35	-34
Δ Elongation at Break	rel.%	-15	-26	-17
Δ Weight	%	+0.6	+0.6	+0.5
Δ Volume	%	+1.2	+1.1	+1.3

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		30 phr Wollastonite AST	30 phr Wollastonite EST	49 phr Barium Sulfate
Storage in Acetic Acid pH3, 168 h / 100 °C				
Hardness	Sh. A	37	not determinable	35
Tensile Strength	MPa	2.6	2.8	10
Elongation at Break	%	54	84	252
Δ Hardness	Sh. A	-30	not determinable	-32
Δ Tensile Strength	%	-86	-86	-37
Δ Elongation at Break	rel.%	-84	-79	-38
Δ Weight	%	+288	+227	+55
Δ Volume	%	+593	+499	+121