



High-Performance Polymers in Plastic-Rubber Composites

Evonik Industries is the creative industrial group from Germany which operates in three business areas: Chemicals, Energy and Real Estate. Evonik is the global leader in specialty chemicals.

The High Performance Polymers Business Line, together with the Acrylic Monomers and Acrylic Polymers Business Lines, is part of the Performance Polymers Business Unit.

High Performance Polymers has specialized in the manufacture of custom-designed products and systems. For over 40 years, the business line has been producing high performance polymers, and is known for its expertise in powder technology — in development, production, application technology, and service.

Expansion of its product portfolio in the area of high-temperature polymers is a logical result of its many years of market success.

Contents

| | | |
|----------|--|-----------|
| 1 | Plastic-Rubber Composites | 4 |
| 1.1 | Hard-Soft Composites | 4 |
| 1.2 | Adhesion without Adhesives | 5 |
| 2 | Two Approaches to Plastic-Rubber Composites | 6 |
| 2.1 | The Two-Stage Process | 6 |
| 2.2 | The One-Stage Process | 6 |
| 2.3 | Economy | 6 |
| 3 | List of Compounds | 8 |
| 4 | Polyphenylene Ether VESTORAN® | 9 |
| 4.1 | Processing | 11 |
| 4.2 | Chemical Resistance | 11 |
| 5 | Polyamides VESTAMID® | 14 |
| 5.1 | Polyphthalamide VESTAMID® HT <i>plus</i> | 14 |
| 5.2 | Polyamide 612 VESTAMID® D | 15 |
| 6 | Examples of Rubber Formulations | 18 |
| 6.1 | SBR Formulation for K&K Composites with VESTORAN® | 18 |
| 6.2 | NR/SBR Formulation for K&K Composites with VESTORAN® | 19 |
| 6.3 | EPDM Formulation for K&K Composites with VESTORAN® and VESTAMID® DX9325 | 20 |
| 6.4 | XNBR Formulation for K&K Composites with VESTAMID® D | 21 |
| 6.5 | HNBR Formulation for K&K Composites with VESTAMID® D, VESTAMID® HT <i>plus</i> | 22 |
| 6.6 | FKM Formulation for K&K Composites with VESTAMID® D, VESTAMID® HT <i>plus</i> | 22 |
| 6.7 | AEM Formulation for Plastic-Rubber Composites with VESTAMID® D, VESTAMID® HT <i>plus</i> | 23 |

1 Plastic-Rubber Composites

The High Performance Polymers Business Line of Evonik manufactures a line of compounds specially modified for the production of adhesive-free plastic-rubber composites.

This brochure describes the plastic-rubber composite process (K&K process) and the compounds available for it.

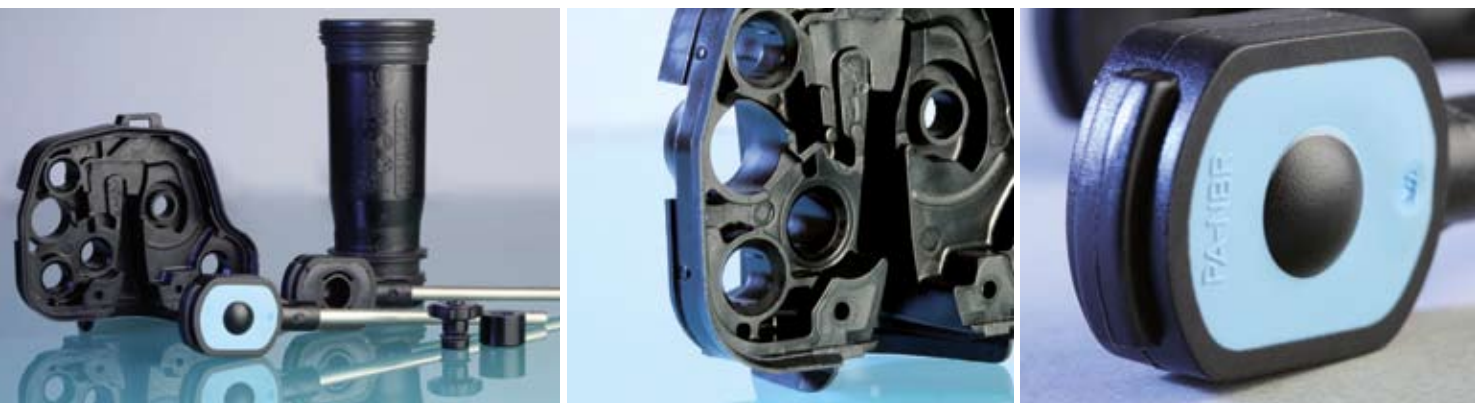
Like all high-performance plastics from the High Performance Polymers Business Line, these compounds meet the highest quality standards. Our quality management system is certified according to ISO 9001:2000 and ISO/TS 16949:2002. Numerous customers have tested this quality management system and confirmed its superiority.

1.1 Hard-Soft Composites

Wherever rubber components must be fastened or fixed, composites consisting of a hard component and an elastomer perform well. They represent an important sector of the rubber industry. Such composites are found in a wide variety of applications, for example, as shock-absorbing bearings in the chassis of motor vehicles, buffers or reinforced seals in engines and machines.

Traditionally, hard components consisted of metal composites. To reduce weight, particularly in vehicles, more and more metal components are being replaced by suitable plastic parts wherever possible. This has two additional advantages: Plastics do not corrode and can be efficiently processed into very complex moldings by injection molding. However, they must be dimensionally stable at the usual vulcanization temperatures of 160–190°C. The manufacture of such complex parts from metal is very expensive. The use of plastics in the design of complex components provides the designer and component developer with much greater latitude.

For the long-term function of composites, particularly under dynamic stress, the adhesion between the hard component and the soft component of the composite is an important criterion. It is usually achieved by adhesives. Combinations of all standard rubber types with most metals and simple plastics are possible. Besides additional process steps for applying the adhesives, protective measures against emissions of the usual solvents and their environmentally correct disposal are required.



1.2 Adhesion without Adhesives

By contrast, the plastic-rubber composite patented by Evonik obviates adhesives. Stable, permanent bonds to suitable rubber blends can be produced without special pre-treatment using special compounds of the series VESTORAN® (polyphenylene ether) and VESTAMID® (polyamide 612, polyphthalamide).

The adhesion is based on several mechanisms, which are represented in Figures 1a–c. When the combination of VESTORAN® and SBR or SBR-containing blends is used, (poly)styrene molecules interdiffuse in the interface. As a result, the substrates are “welded” together (Figure 1a). The composite of VESTORAN® with peroxidic cross-linked EPDM consists of stable carbon-carbon bonds formed by radicals (Figure 1b). In the case of the VESTAMID® types, in combination with XNBR, peroxidic crosslinking produces not only carbon-carbon bonds but also amide groups, which ensure permanent adhesion (Figure 1c). The type of the very stable bond of fluororubber to polyamides is not yet completely understood, an ionic reaction with the acid modified rubber could be feasible.

Bonding mechanisms

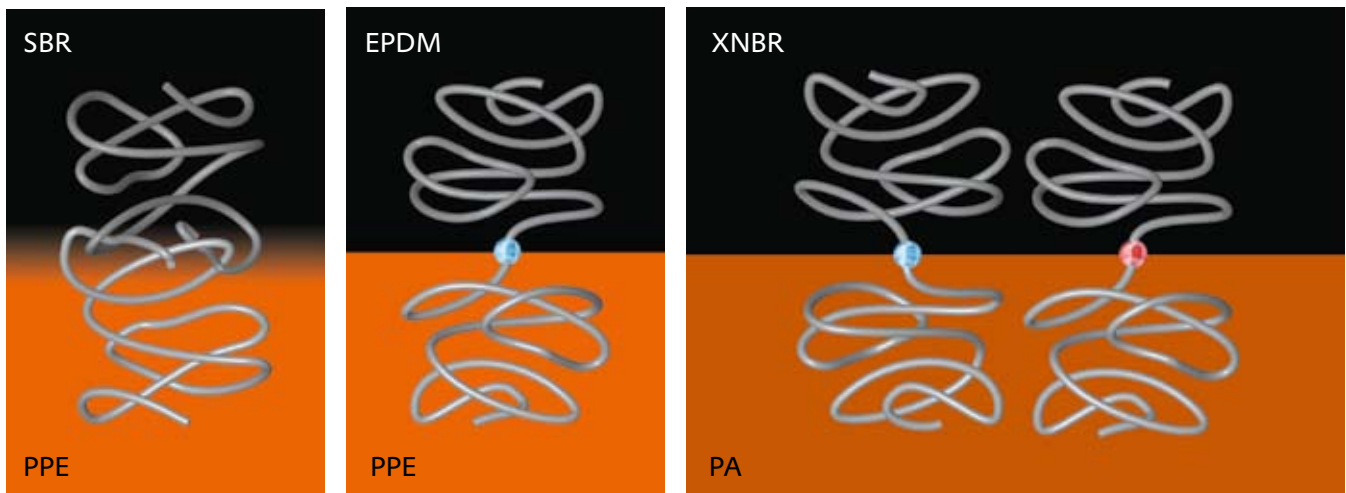


Figure 1a
Bonding of polyphenylene ether to SBR by diffusion of styrene segments

Figure 1b
Radical bonding of polyphenylene ether to EPDM by peroxides

Figure 1c
Radical bonding of polyamides to XNBR by peroxides and amide groups

2 Two Approaches to Plastic-Rubber Composites

Depending on existing technical and plant conditions, two processes are available for manufacturing adhesive-free composites.

2.1 The Two-Stage Process

The two-stage process is almost identical with the conventional production of rubber-metal and plastic-rubber components. The plastic part is manufactured separately or supplied by an injection molder. The rubber compound is applied to this insert and vulcanized. However, the intermediate step of applying the adhesives is obviated.

This process is particularly useful when the vulcanization time is substantially longer than the cooling time of the associated plastic component. The two process steps can be optimally designed independently of each other. Investments in new machines are not necessary.

2.2 The One-Stage Process

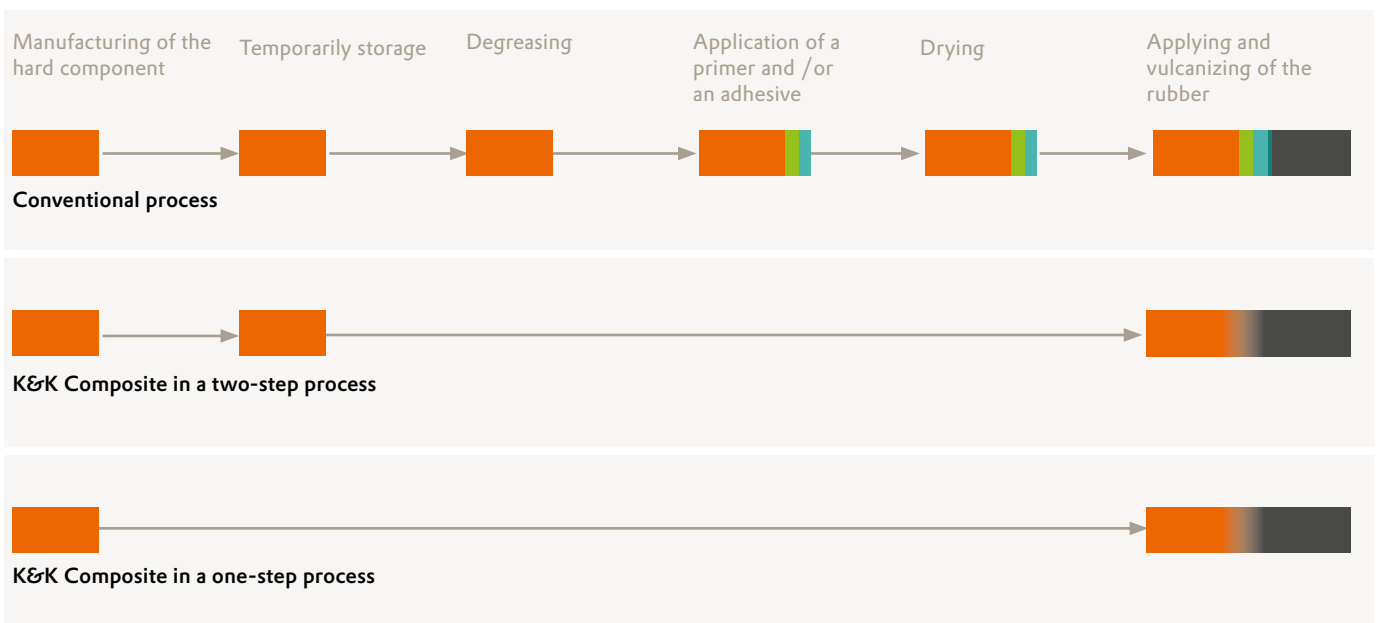
If there is little or no difference between cooling time and vulcanization time, the one-stage process is an option. By obviating adhesives, the composites can be manufactured in a common tool without intermediate steps, similarly to the two-component injection molding process. To accomplish this, the injection molding machine must be equipped with a rubber cylinder and a thermoplastic cylinder. Each cavity, that is, the thermoplastic cavity and the rubber cavity, is situated in one half of a common tool. The plastic part is manufactured in the "cold" half of the tool. It is then transferred, for example, with an index plate, transfer handling, or rotation molding into the "hot" half. Here the rubber formulation is applied and vulcanized. At the same time a new plastic molding is formed in the cold half. After the finished composite is dumped from the hot half, the cycle starts again. This process sequence is shown in Figure 3.

2.3 Economy

The manufacturing process can be largely automated by eliminating adhesives. Repeated handling of the parts is obviated. Thus, several sources of error are eliminated and the reject rate decreases. Depending on plant-specific conditions, cost savings of up to 30% can be achieved.

For comparing costs between the conventional process and the K&K process, we provide a cost estimate sheet upon request. Simply get in touch with the specified representative.

Figure 2
Process steps for composites



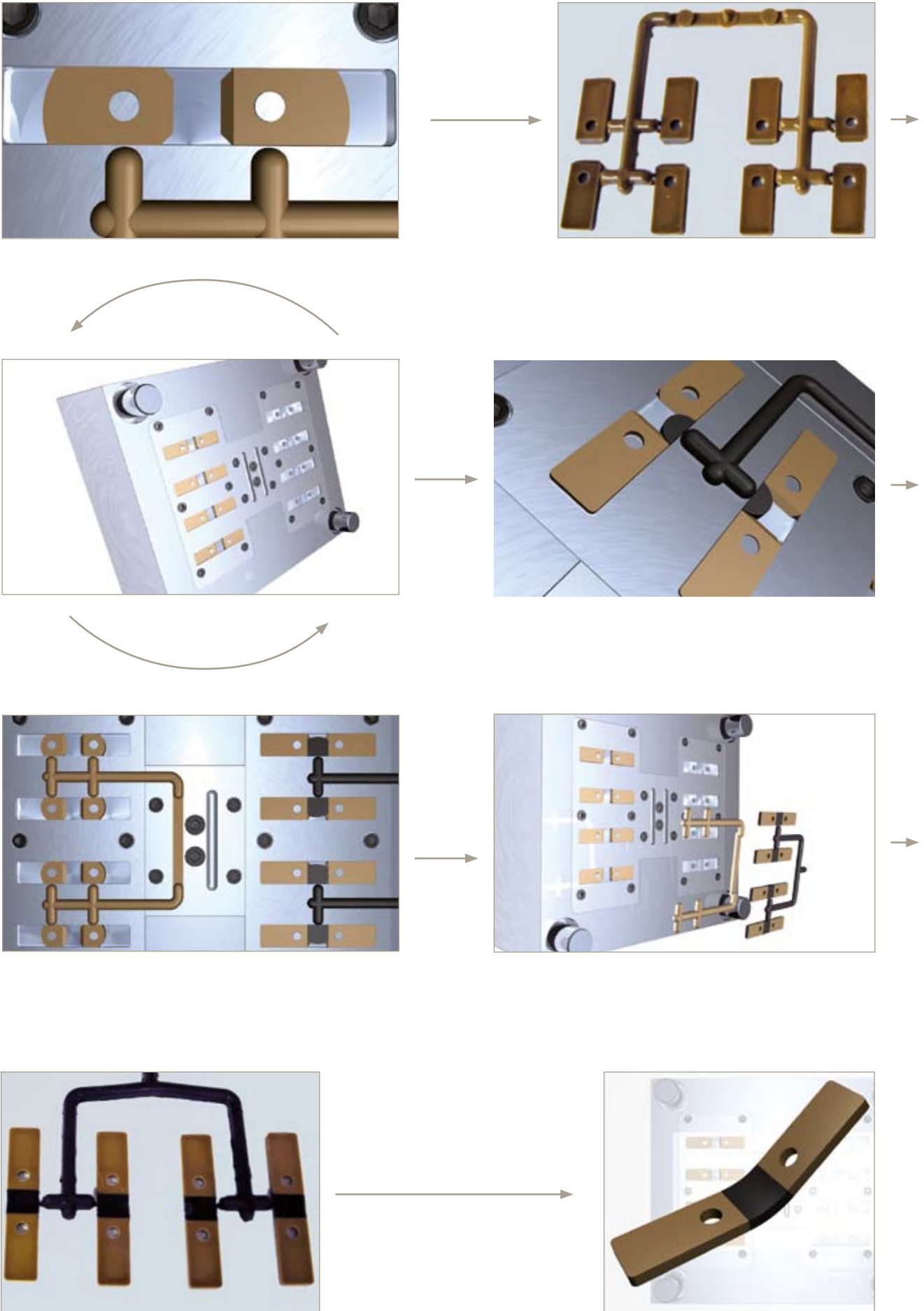


Figure 3
 Manufacture of a plastic-rubber composite in the one-stage process

3 List of Compounds

Table 1: Combination possibilities of plastic-rubber composites

| Rubber | VESTORAN® (PPE) | VESTAMID® (PA 612) | VESTAMID® HTplus (PPA) |
|----------|-----------------|--------------------|------------------------|
| ACM | - | A | * |
| AEM/EAM | - | A | A |
| EPDM | P | P | * |
| FPM | - | BIS/P/A | P |
| HNBR | - | P | P |
| NR/SBR | S | - | - |
| SBR | S | - | - |
| SBR/EPDM | S | - | - |
| SBR/NBR | S | - | - |
| VMQ | - | P | P |
| XNBR | - | P | * |

S = Sulphur, P = Peroxide, A = Amine, BIS = Bisphenol, *under evaluation

Table 2: List of compounds available for adhesive-free plastic-rubber composites

| Compound | Filler | Combined with | Cross-Linking System | Applications |
|------------------------|-----------------------------------|---------------------------------|------------------------------|---|
| VESTORAN® 1900 | | SBR, NR/SBR, NBR/SBR, EPDM | Sulfur Peroxide | Vibration absorbers, shock absorbing bushings, reinforced profiles, seals |
| VESTORAN® 1900GF20 | 20% glass fibers | | | |
| VESTAMID® X7094 | | XNBR, HNBR, AEM, FPM | Peroxide, bisphenol, amine | Oil-resistant seals, moldings, pencil coil ducts, valve flaps |
| VESTAMID® X7099 | 20% glass fibers | | | |
| VESTAMID® DX9301 | 4% graphite | | | |
| VESTAMID® DX9320 | 10% glass fibers, impact-modified | | | |
| VESTAMID® DX9321 | 20% glass fibers, impact-modified | | | |
| VESTAMID® DX9322 | 15% ground glass fibers | | | |
| VESTAMID® DX9323 | 35% glass fibers, impact-modified | | | |
| VESTAMID® DX9325 | 40% glass fibers, impact-modified | EPDM, XNBR, HNBR, AEM, FPM, NBR | Peroxide, bisphenol, amine | Shock absorbing bushings, seals |
| VESTAMID® HTplus R1033 | 30% glass fibers | HNBR, FPM, AEM | Peroxide, bisphenol*, amine* | Heat resistant vibration absorbers, shock absorbing bushings, dumping parts, pencil coil ducts, valve flaps |
| VESTAMID® HTplus R1035 | 50% glass fibers | | | |
| VESTAMID® HTplus R1133 | 30% glass fibers | EPDM, AEM, FPM, XNBR | | |

*under evaluation

4 Polyphenylene Ether VESTORAN®

VESTORAN® is the registered trademark of Evonik for compounds based on poly-2,6-dimethyl-1,4-phenylene ether (PPE). The amorphous material has high heat deflection temperature. Moldings of VESTORAN® have very low mold shrinkage and warpage. VESTORAN® is hot water-resistant. The water absorption is very low. It is resistant to alkalis and acids but less resistant to fats, oils and fuels. Section 4.2 provides details on chemical resistance.

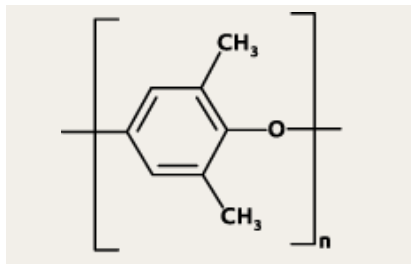


Figure 4
Molecular structure of polyphenylene ether

Four VESTORAN® grades are available for adhesive-free plastic-rubber composites:

- VESTORAN® 1900 natural and 1900 black
- VESTORAN® 1900GF20 light ivory and 1900GF20 black

These grades can be combined with SBR and SBR blends, such as NR/SBR; the SBR portion should be at least 20 wt%. These rubbers are to be crosslinked with sulfur. Applications of such combinations include vibration bushings and shock absorbers in the chassis of motor vehicles.

Combinations with EPDM compounds that are peroxidically crosslinked perform well. Examples of applications are reinforced profiles and seals.

Examples of SBR, NR/SBR and EPDM formulations are shown in Chapter 7.



Table 3: Properties of polyphenylene ether compounds for plastic-rubber composites

| Properties | | Test method | Unit | VESTORAN® 1900 | VESTORAN® 1900GF20 |
|--|------------------|--|-------------------------|-----------------------|-----------------------|
| Physical, thermal and mechanical properties | | | | | |
| Density | 23°C | ISO 1183 | g/cm ³ | 1.04 | 1.19 |
| Melt volume-flow rate (MVR) | 300°C/21.6 kg | ISO 1133 | cm ³ /10 min | ca. 40 | ca. 15 |
| Tensile test | | ISO 527-1/-2 | | | |
| Stress at yield | | | MPa | 60 | |
| Strain at yield | | | % | 6 | |
| Tensile strength | | | MPa | | 110 |
| Strain at break | | | % | >50 | 3 |
| Tensile modulus | | ISO 527-1/-2 | MPa | 2000 | 5600 |
| Flexural modulus | | ISO 178 | MPa | 2400 | 5700 |
| CHARPY impact strength* | 23°C | ISO 179/1eU | kJ/m ² | 250 P | 50 C |
| CHARPY notched impact strength* | 23°C | ISO 179/1eA | kJ/m ² | 25 C | 12 C |
| Temperature of deflection under load | | ISO 75-1/-2 | | | |
| Method A | 1.8 MPa | | °C | 170 | 185 |
| Method B | 0.45 MPa | | °C | 190 | 190 |
| Vicat softening temperature | | ISO 306 | | | |
| Method A | 10 N | | °C | 190 | 200 |
| Method B | 50 N | | °C | 185 | 190 |
| Flammability acc. UL94 | 0.8 mm | ISO 60695 | | HB | HB |
| | 1.6 mm | | | HB | HB |
| Water absorption | 23°C, saturation | ISO 62 | % | 0.4 | 0.4 |
| Processing shrinkage | | Determined on 2 mm sheets with film gate at rim, mold temperature 80°C | | | |
| in flow direction | | | % | approx. 0.9 | 0.5 |
| in transverse direction | | | % | approx. 0.8 | 0.6 |
| Electrical Properties | | | | | |
| Relative permittivity | 100 Hz | IEC 60250 | | 2.6 | 2.9 |
| | 1 MHz | | | 2.9 | 2.7 |
| Dissipation factor | 100 Hz | IEC 60250 | | 8 · 10 ⁻⁴ | 8 · 10 ⁻⁴ |
| | 1 MHz | | | 16 · 10 ⁻⁴ | 18 · 10 ⁻⁴ |
| Electric strength | K20/P50 | IEC 60243-1 | kV/mm | 40 | 33 |
| Comparative tracking index | | IEC 60112 | | | |
| Test solution A | CTI | | | 225 | 200 |
| | 100 drops value | | | 200 | 175 |
| Volume resistivity | | IEC 60093 | Ohm · m | 10 ¹³ | 10 ¹³ |
| Surface resistance R _{OA} | | IEC 60093 | Ohm | 10 ¹⁴ | 10 ¹³ |
| Electrolytic corrosion | | IEC 60426 | Stage | A1 | A1 |

4.1 Processing VESTORAN®

Pre-drying

Although VESTORAN® absorbs very little moisture, pre-drying in a circulating or vacuum dryer is extremely important. To prevent damage to the material, drying conditions should not exceed 110–120°C for 2 hours. The pre-dried granulate must be introduced hot into the machine hopper. The dwell time of the melt in the cylinder should be less than 5 minutes.

Machine parameters

Screw: L/D ratio min. 20:1, compression ratio 2:1 to 3:1

Nozzle: Diameter greater than 3 mm

Injection pressure: 800–1600 bar

Holding pressure: 50–80% of injection pressure

Specific back pressure: 5–10 bar

Temperature settings:

Cylinder: 280/300/320/320°C

Nozzle: 310°C

Melt: 300–330°C

The melting temperature should not exceed 340°C to prevent thermal damage to the PPE.

Mold

Externally heated hot runner systems must be used. Approximately 0.05 mm deep venting channels should be placed near the welding lines.

Temperature settings for separate manufacture of the moldings (two-stage process):

VESTORAN® 1900 80–90°C

VESTORAN® 1900GF20 130–140°C

Temperature settings for the one-stage process:

VESTORAN® 1900 180°C

VESTORAN® 1900GF20 180°C

The higher mold temperature in the one-stage process enables the molding heat to be utilized for a shorter vulcanization time of the rubber component. An exhausting device above the injection molding machine is strongly recommended.

Handling VESTORAN® moldings in the two-stage process

When pre-molded components are used for the plastic-rubber composites, no mold release agents may be used. The VESTORAN® surfaces must be free of grease and dust. Intermediate storage of the moldings is done in the dark, for example, in black polyethylene bags. Further processing within two weeks is recommended. Contaminated surfaces can be cleaned by wiping them off with toluene.



4.2 Chemical Resistance of VESTORAN®

The stress cracking susceptibility test according to ISO 4599 under the influence of different media is a criterion for chemical resistance (bent strip test, 3.5% outer fiber strain with basic grades; 2.7% outer fiber strain in the case of glass fiber-reinforced grades). The resistance is dependent on temperature but also on the stress state of the test specimen. Therefore, we recommend using a test under field conditions to determine whether the requirements are met.



Table 4: Chemical resistance of VESTORAN®

| Medium | | Test temperature (°C) | Basic grades | Glass fiber-reinforced grades |
|-----------------------------------|------|-----------------------|--------------|-------------------------------|
| Acetic acid | 50% | 80 | + | + |
| | 100% | 20 | - | - |
| Acetone | | 20 | - | - |
| Ammonia | 25% | 20 | + | + |
| Antifreeze | 50% | 100 | + | + |
| | 100% | 100 | + | + |
| Brake fluid (ATE DOT 4) | | 20 | - | - |
| Cyclohexane | | 20 | - | - |
| Diethylene glycol | 50% | 20 | + | + |
| | 99% | 20 | + | + |
| 1,4-Dioxane | | 20 | - | - |
| Ethanol | | 20 | +/- | +/- |
| Ethyl acetate | | 20 | - | - |
| Ethylene glycol | | 20 | + | + |
| Formic acid | 80% | 20 | + | + |
| | 100% | 20 | + | + |
| Glycerin | | 20 | + | + |
| Hydraulic fluid (Shell Tegula 32) | | 20 | - | - |
| Hydrochloric acid | 10% | 20 | + | + |
| | 35% | 20 | + | + |
| Isobutanol | | 20 | +/- | +/- |
| Isopropanol | | 20 | +/- | +/- |
| Lubricating oil (BP Energrease) | | 80 | - | - |
| Methanol | | 20 | +/- | +/- |
| Methyl ethyl ketone | | 20 | - | - |
| Methyl-tert.-butyl ether (MTB) | | 20 | - | - |
| Motor oil SAE 15-W40 | | 80 | - | - |
| N,N-Dimethylformamide | | 20 | - | - |
| Nitric acid | 65% | 20 | - | - |
| Oxalic acid | 5% | 80 | + | + |
| Paraffin oil | | 20 | + | + |
| Phosphoric acid | 10% | 20 | + | + |
| | 85% | 20 | + | + |
| Potassium hydroxide solution | 10% | 20 | + | + |
| | 60% | 20 | + | + |
| Silicone oil 740 | | 20 | + | + |
| | | 80 | + | + |
| Sodium hydroxide solution | 10% | 80 | + | + |
| | 50% | 20 | + | + |
| Sulfuric acid | 10% | 80 | + | + |
| | 25% | 20 | + | + |
| | 98% | 20 | - | - |
| Toluene | | 20 | - | - |
| Water | | 100 | + | + |

+resistant, +/-somewhat resistant, -not resistant

5 Polyamides VESTAMID®

Evonik manufactures and sells various polyamide (PA) grades. The polyamide 612 products are named VESTAMID® D, the polyphthalamide (PPA) grades are supplied under the trade name VESTAMID® HTplus.

5.1 Polyphthalamide

VESTAMID® HTplus

VESTAMID® HTplus belongs to the family of polyphthalamide (PPA) polymers. Evonik have combined high temperature durability, excellent chemical resistance against the most automotive fluids, and outstanding mechanical properties with the flexibility of multiple process technologies. Our latest development exploits the high heat deflection temperature of more than 280°C and dimensional stability of VESTAMID® HTplus, especially in the range of 120 to 140°C, and adds the special functionality of direct bonding to a variety of elastomers. Compared with PA 66 and PA 612, VESTAMID® HTplus features also higher strength and stiffness, especially in contact with moisture, a high long-term heat resistance up to 150°C, and a low tendency to creep. Due to higher heat deflection temperature of PPA compared to PA 612 it is pos-

sible to vulcanize also thin thermoplastic parts together with rubber up to 190°C without any deformation of the plastic part.

For direct rubber bonding three heat-stabilized grades are available:

- VESTAMID® HTplus R1033 and R1133 are 30% glass fiber-reinforced,
- VESTAMID® HTplus R1035 contains 50% glass fibers.

These compounds are especially for manufacturing parts subjected to high temperature.

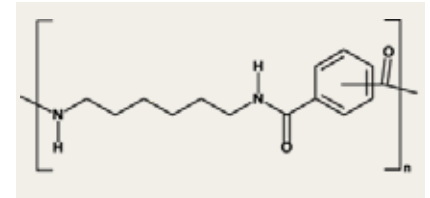


Figure 5
Molecular structure of polyphthalamide

Table 5: Properties of VESTAMID® HTplus compounds for plastic-rubber composites

| Property | Test method | Unit | R1033 | R1133 | R1035 | |
|---------------------------------|--------------|-------------------|-------------------|---------|---------|------|
| Glass fiber content | | % | 30 | 30 | 50 | |
| Density | 23°C | ISO 1183 | g/cm ³ | 1.43 | 1.40 | 1.64 |
| Tensile test | ISO 527-1/-2 | | | | | |
| Tensile strength | | MPa | 180 | 140 | 260 | |
| Strain at break | | % | 2.0 | 1.5 | 1.8 | |
| Tensile modulus | ISO 527-1/-2 | MPa | 11000 | 10500 | 17000 | |
| CHARPY impact strength* | ISO 179/1eU | | | | | |
| 23°C | | kJ/m ² | 45 C | 29 C | 70 C | |
| -40°C | | kJ/m ² | 30 C | 23 C | 50 C | |
| CHARPY notched impact strength* | ISO 179/1eA | | | | | |
| 23°C | | kJ/m ² | 7 C | 6 C | 12 C | |
| -40°C | | kJ/m ² | 7 C | 6 C | 12 C | |
| Vicat softening temperature | ISO 306 | | | | | |
| Method A | 10 N | °C | 308 | 300 | 308 | |
| Method B | 50 N | °C | 275 | 275 | 282 | |
| Melt temperature | | °C | 330-340 | 330-340 | 330-340 | |
| Mold temperature | | °C | 140-180 | 140-180 | 140-180 | |

*C = complete break

5.2 Polyamide 612 VESTAMID® D

Compounds are available in the D series specifically for adhesive-free manufacture of plastic-rubber composites. As partially crystalline materials, they feature excellent chemical resistance, particularly toward greases, oils and fuels. Besides very good sliding friction properties, PA 612 compounds show appreciably less water absorption than PA 6 or PA 66.

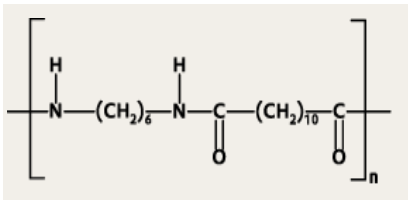


Figure 6
Molecular structure of polyamide 612

Chemical resistance

The chemical resistance of PA 612 is comparable to that of PA 12. Polyamide 612 generally displays outstanding resistance to fuels, lubricants, greases, oils, and most industrial solvents. Polar solvents can cause reversible swelling, especially at elevated temperatures. This will generally be connected with a drop in strength (plasticizer effect). In practice, the original characteristics will be restored after the solvent has evaporated. Liquids that have a particularly high affinity to the carbonamide groups of the polyamides can act as solvents for PA 612 at higher temperatures. Examples are phenols, cresols, benzyl alcohol, and particular chloro-hydrocarbons. Due to their low water absorption, PA 612 compounds exhibit very good resistance to aqueous agents, such as alkali solutions, saline solutions, and cleaners. Their resistance to aqueous acids is limited, depending on the temperature, time, and concentration. In general, concentrated acids will lead to a more or less rapid drop in relative molar mass (embrittlement). Concentrated sulfuric acid and formic acid will dissolve PA 612.

Rubber combinations

The properties of the VESTAMID® grades suitable for plastic-rubber composites are listed in Table 6. Compounds with different glass fiber contents and, in some cases, with impact modification are available. For manufacture of oil-resistant and fuel-resistant seals and moldings, they can be combined with appropriate rubber blends, for example, based on XNBR rubber, partially saturated HNBR rubber and FPM rubber. Moldings for the two-stage plastic-rubber process should be stored in a dust-free atmosphere and processed within three months.

Examples for known rubber formulations are found in Chapter 7.



Table 6: Properties of VESTAMID® polyamide 612 compounds for plastic-rubber composites

| Properties | | Test method | Unit | X7094 black | DX9301 black 4% graphite | |
|--|-------------------------|-------------------------------|-------------------|----------------------------------|-----------------------------|-----|
| Physical, thermal and mechanical properties | | | | | | |
| Density | 23°C | ISO 1183 | g/cm ³ | 1.06 | 1.09 | |
| Melting temperature | peak temperature | ISO 11357 | °C | 215 | 215 | |
| | 2 nd heating | | | | | |
| Temperature of deflection under load | | ISO 75-1/-2 | | | | |
| | Method A | | 1.8 MPa | °C | 60 | 85 |
| | Method B | | 0.45 MPa | °C | 150 | 185 |
| Vicat softening temperature | | ISO 306 | | | | |
| | Method B | | 50 N | °C | 185 | 187 |
| Linear thermal expansion | 23°C - 55°C | ISO 11359 | | | | |
| | longitudinal | | | 10 ⁻⁴ K ⁻¹ | 1.3 | |
| | transverse | | | 10 ⁻⁴ K ⁻¹ | 1.1 | |
| Flammability acc. UL94 | 1.6 mm | IEC 60695 | | HB | | |
| | 3.2 mm | | | HB | | |
| Water absorption | 23°C, saturation | ISO 62 | % | 2.8 | 2.7 | |
| Moisture absorption | 23°C, 50 % r.F. | ISO 62 | % | 1.0 | 1.0 | |
| Mold shrinkage | in flow direction | Specimen 127·12.7·3.2 mm | % | 1.3 | 1.2 | |
| | in transverse direction | Processing acc. ISO 1874-2 | % | 1.1 | 1.4 | |
| Tensile test | | ISO 527-2/1 A | | | | |
| | Stress at yield | | MPa | 60 | | |
| | Strain at yield | | % | 5 | | |
| | Stress at break | | MPa | | 65 | |
| | Strain at break | | % | 8 | 7 | |
| Tensile modulus | | ISO 527-2/1 A | MPa | 2200 | 2700 | |
| CHARPY impact strength* | 23°C | ISO 179/1eU | kJ/m ² | N | 115 C | |
| | -30°C | | kJ/m ² | N | 110 C | |
| CHARPY notched impact strength* | 23°C | ISO 179/1eA | kJ/m ² | 6 C | 4 C | |
| | -30°C | | kJ/m ² | 7 C | 3 C | |
| Electrical properties | | | | | | |
| Relative permittivity | 100 Hz | IEC 60250 | | 4.4 | | |
| | 1 MHz | | | 3.9 | | |
| Dissipation factor | 100 Hz | IEC 60250 | 10 ⁻⁴ | 590 | | |
| | 1 MHz | | 10 ⁻⁴ | 390 | | |
| Electric strength | K20/P50 | IEC 60243-1 | KV/mm | 30 | | |
| Comparative tracking index | CTI | IEC 60112 | | | | |
| | Test solution A | | | | | |
| | 100-drop-value | | | > 600 | | |
| Volume resistivity | | IEC 60093 | Ohm · cm | 10 ¹⁴ | | |

*N = no break, C = complete break

| DX9320 black 10% glass fibers | DX9322 black 15% milled glass fibers | X7099 black 20% glass fibers | DX9321 black 20% glass fibers | DX9323 black 35% glass fibers | DX9325 black 40% glass fibers |
|----------------------------------|---|---------------------------------|----------------------------------|----------------------------------|----------------------------------|
| 1.12 | 1.17 | 1.20 | 1.19 | 1.33 | 1.37 |
| 215 | 215 | 210 | 215 | 215 | 212 |
| | | | | | |
| 183 | 114 | 190 | 189 | 196 | 195 |
| 201 | 186 | 210 | 208 | 213 | 210 |
| | | | | | |
| 199 | 194 | 205 | 207 | 209 | |
| | | | | | |
| 0.7 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 |
| 0.8 | 0.6 | 0.7 | 0.7 | 0.8 | |
| HB | HB | HB | HB | HB | HB |
| | | HB | | HB | HB |
| 2.6 | 2.4 | 2.0 | 2.0 | 1.9 | 1.9 |
| 1.0 | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 |
| | | | | | |
| 1.29 | 1.92 | 0.55 | 0.66 | 0.35 | 0.23 |
| 0.97 | 0.93 | 1.05 | 0.88 | 1.02 | 0.8 |
| | | | | | |
| | 63 | | | | |
| | 8 | | | | |
| 82 | 59 | 118 | 115 | 148 | 150 |
| 10 | 18 | 5 | 5 | 5 | 4 |
| 3700 | 3150 | 5600 | 5700 | 8900 | 9400 |
| 81 C | 46 C | 80 C | 93 C | 90 C | 100 C |
| 96 C | 43 C | 60 C | 106 C | 105 C | 104 C |
| 11 C | 4 C | 10 C | 18 C | 22 C | 22 C |
| 5 C | 3 C | 7 C | 11 C | 15 C | 16 C |
| | | | | | |
| 4.3 | 4.3 | 4.4 | 4.4 | 4.8 | |
| 3.1 | 3.1 | 3.9 | 3.1 | 3.6 | |
| 470 | 430 | 650 | 500 | 610 | |
| 466 | 493 | 430 | 470 | 320 | |
| | | 38 | | 39 | |
| | | | | | |
| > 600 | > 600 | | > 600 | >600 | |
| 600 | 575 | | 600 | 575 | |
| 10 ¹⁴ | 10 ¹⁴ | 10 ¹⁴ | 10 ¹⁴ | 10 ¹⁴ | |



6 Examples of Rubber Formulations

6.1 SBR Formulation for Plastic-Rubber Composites with VESTORAN®

| Formulation No.: | | | | RD 3530 |
|------------------------------------|------------|-----------------|-----|----------------|
| SBR 1500 | | | | 100 |
| Carbon black N 330 (HAF) | | | | 50 |
| ZnO, RS | | | | 3.0 |
| Stearic acid | | | | 1.0 |
| Vulcazit® NZ (TBBS) | | | | 1.0 |
| Sulfur | | | | 1.75 |
| ML (1+4) | 100°C | | | 85 |
| Vulcameter | 180°C | t ₁₀ | min | 2.8 |
| | | t ₉₀ | min | 5.9 |
| Vulcanization 180°C; 10 min | | | | |
| Hardness | 23°C | Shore A | | 67 |
| Hardness | 75°C | Shore A | | 63 |
| Tensile strength | | | MPa | 18.6 |
| Strain at break | | | % | 410 |
| Modulus 100% strain | | | MPa | 2.5 |
| Modulus 200% strain | | | MPa | 6.5 |
| Modulus 300% strain | | | MPa | 12.0 |
| Impact resilience | 23°C | | % | 45 |
| Impact resilience | 75°C | | % | 53 |
| Compression set | 22 h; 70°C | | % | 20 |



**6.2 NR/SBR Formulation for Plastic-Rubber Composites
with VESTORAN®**

| Formulation No.: | | | | RD 5010 |
|-----------------------------------|-------|-----------------|-----|----------------|
| NR | | | | 80 |
| SBR 1500 | | | | 20 |
| Carbon black N 772 (SRF-HM) | | | | 59 |
| ZnO, RS | | | | 4 |
| Stearic acid | | | | 1.0 |
| Antilux® 600 | | | | 2 |
| Vulcanox® 4020 (IPPD) | | | | 2.0 |
| Vulcazite® CZ (CBS) | | | | 0.65 |
| Vulcalent® E | | | | 0.2 |
| Vulcanox® HS (TMQ) | | | | 1.2 |
| Sulfur | | | | 4.0 |
| ML (1+4) | 100°C | | | 67 |
| Vulcameter | 180°C | t ₁₀ | min | 0.5 |
| | | t ₉₀ | min | 2.0 |
| Vulcanization 180°C; 4 min | | | | |
| Hardness | 23°C | Shore A | | 60 |
| Hardness | 75°C | Shore A | | 57 |
| Tensile strength | | | MPa | 8.7 |
| Strain at break | | | % | 260 |
| Modulus 100% strain | | | MPa | 2.1 |
| Modulus 200% strain | | | MPa | 5.7 |
| Modulus 300% strain | | | MPa | 11.6 |
| Impact resilience | 23°C | | % | 49 |
| Impact resilience | 75°C | | % | 59 |



6.3 EPDM Formulation for Plastic-Rubber Composites with VESTORAN® and VESTAMID® DX9325



| Formulation No.: | | | | RD 5162 |
|------------------------------------|------------|-----------------|-------------------|----------------|
| Buna EP G 6470 | | | | 90 |
| VESTENAMER® 8012 | | | | 10 |
| Carbon Black N 539 (FEF-LS) | | | | 72 |
| Paraffin Oil | | | | 51 |
| ZnO, RS | | | | 5.0 |
| Vulcanox® HS (TMQ) | | | | 1.0 |
| TRIM/S | | | | 1.25 |
| Perkadox® 14/40 | | | | 5.5 |
| ML (1+4) | 100°C | | | 46 |
| Vulcameter | 180°C | t ₁₀ | min | 0.65 |
| | | t ₉₀ | min | 5.2 |
| Density | | | g/cm ³ | 0.96 |
| Vulcanization 180°C; 20 min | | | | |
| Hardness | 23°C | Shore A | | 64 |
| Hardness | 75°C | Shore A | | 53 |
| Tensile strength | | | MPa | 13.4 |
| Strain at break | | | % | 420 |
| Modulus 100% strain | | | MPa | 2 |
| Modulus 200% strain | | | MPa | 5 |
| Modulus 300% strain | | | MPa | 8.6 |
| Impact resilience | 23°C | | % | 59 |
| Impact resilience | 75°C | | % | 61 |
| Compression set | 22 h; 70°C | | % | 13.3 |





6.4 XNBR Formulation for Plastic-Rubber Composites with VESTAMID® D

| Formulation No.: | | | | RD 3731 blue |
|------------------------------------|------------|-----------------|-----|--------------|
| Nipol® 1472 (or Chemigum® NX 775) | | | | 100 |
| Vulkasil® C | | | | 60 |
| Polestar® 200 (Calc, Clay) | | | | 20 |
| Vulcanol® 88 | | | | 10 |
| Titandioxide | | | | 3.0 |
| Oppasin® blue | | | | 2.0 |
| Stearic acid | | | | 1.0 |
| BDMA | | | | 0.8 |
| Perkadox® BC40-B pd | | | | 5.0 |
| ML (1+4) | 100°C | | | 69 |
| Vulcameter | 180°C | t ₁₀ | min | 0.5 |
| | | t ₉₀ | min | 2.8 |
| Vulcanization 180°C; 10 min | | | | |
| Hardness | 23°C | Shore A | | 76 |
| Hardness | 75°C | Shore A | | 72 |
| Tensile strength | | | MPa | 9.8 |
| Strain at break | | | % | 400 |
| Modulus 100% strain | | | MPa | 9.8 |
| Modulus 200% strain | | | MPa | 6.1 |
| Modulus 300% strain | | | MPa | 7.7 |
| Impact resilience | 23°C | | % | 29 |
| Impact resilience | 75°C | | % | 49 |
| Compression set | 22 h; 70°C | | % | 18 |

**6.5 HNBR Formulation for Plastic-Rubber Composites with VESTAMID® D,
VESTAMID® HTplus**

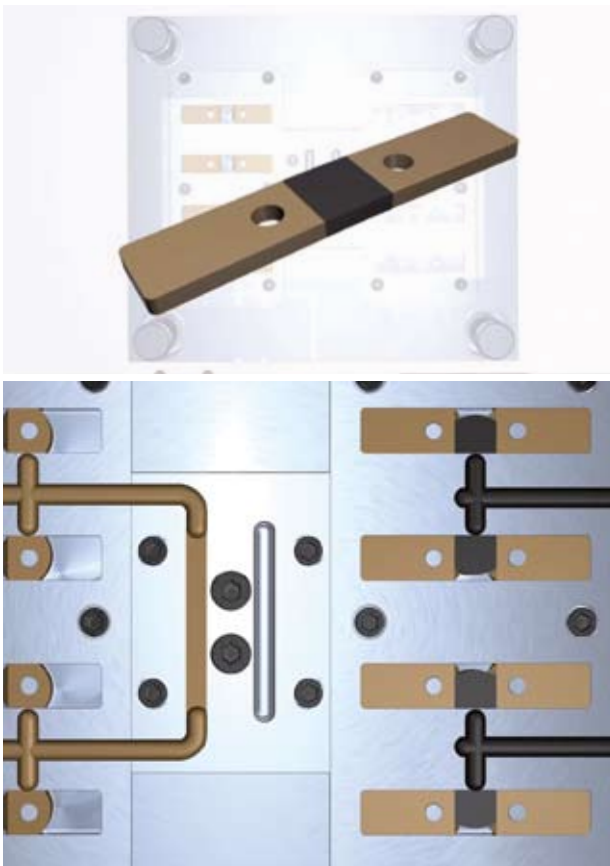
| Formulation No.: | | | | RD 5080/3 |
|-----------------------------------|-------|-----------------|-----|------------------|
| Zetpole® 3110 | | | | 100 |
| Carbon black N 550 (FEF) | | | | 65 |
| Rhenosin® W-759 | | | | 10 |
| ZnO | | | | 2 |
| HVA 2 | | | | 4 |
| Perkadox® 14/40 | | | | 7 |
| ML (1+4) | 100°C | | | 122 |
| Vulcameter | 180°C | t ₁₀ | min | 0.9 |
| | | t ₉₀ | min | 2.8 |
| Vulcanization 180°C; 5 min | | | | |
| Hardness | 23°C | Shore A | | 77 |
| Hardness | 75°C | Shore A | | 73 |
| Tensile strength | | | MPa | 14 |
| Strain at break | | | % | 117 |
| Modulus 100% strain | | | MPa | 12.2 |
| Impact resilience | 23°C | | % | 45 |
| Impact resilience | 75°C | | % | 58 |
| Compression set | | | % | 7 |

**6.6 FKM Formulation for Plastic-Rubber Composites with VESTAMID® D,
VESTAMID® HTplus**

| Formulation No.: | | | | RD 3367 |
|--|-------|-----------------|-----|----------------|
| Dai EI™ | | | | 100 |
| Carbon black N 990 (MT) | | | | 15 |
| Rhenofit® D/A | | | | 3 |
| Innovox® OH | | | | 6 |
| ML (1+4) | 100°C | | | 109 |
| Vulcameter | 180°C | t ₁₀ | min | 1.4 |
| | | t ₉₀ | min | 4.1 |
| Vulcanization 170°C; 10 min, Tempering 175°C; 24h | | | | |
| Hardness | 23°C | Shore A | | 58 |
| Hardness | 75°C | Shore A | | 52 |
| Tensile strength | | | MPa | 7.7 |
| Strain at break | | | % | |
| Modulus 100% strain | | | MPa | 1.7 |
| Modulus 200% strain | | | MPa | 3.5 |
| Modulus 300% strain | | | MPa | 5.8 |
| Impact resilience | 23°C | | % | 10 |
| Impact resilience | 75°C | | % | 57 |

**6.7 AEM Formulation for Plastic-Rubber Composites with VESTAMID® D,
VESTAMID® HTplus**

| Formulation No.: | | | RD 70849 | |
|--|-------|-----------------|-----------------|------|
| Vamac® G | | | | 100 |
| Naugard® 445 | | | | 2 |
| Armeen® 18D | | | | 0.5 |
| Stearic acid | | | | 2 |
| Gafac® RL-210 | | | | 0.5 |
| Carbon black N-774 | | | | 55 |
| DIAK No 1 | | | | 1.25 |
| Diphenylguanidine (DPG) | | | | 4 |
| ML (1+4) | 100°C | | | 16 |
| Vulcameter | 180°C | t ₁₀ | min | |
| | | t ₉₀ | min | |
| Vulcanization 177°C; 20 min, Tempering 175°C; 24h | | | | |
| Hardness | 23°C | Shore A | | 68 |
| Tensile strength | | | MPa | 13.4 |
| Strain at break | | | % | 2.4 |
| Modulus 100% strain | | | MPa | 6.4 |
| Modulus 200% strain | | | MPa | 510 |



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