Crosslinking of carboxylated nitrile rubbers with resol resins

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SUMMARY

This paper discusses at length the metal oxide and sulfur-free crosslinking of rubber compounds for carboxylated nitrile rubber (XNBR) using resols based on p-alkyl phenols (resol crosslinking). It demonstrates that, with the best grade and dosage of resol and the right Krynac X nitrile rubber grade, such a compound can be adjusted to match the overall property profile resulting from traditional crosslinking with zinc oxide/sulfur with even better processing characteristics. Significant improvements can be achieved, for instance in the compression set characteristics. Resol crosslinking is sensitive to the grade of rubber used. The best and most balanced property profile can be achieved with XNBR grades containing 1% carboxylic acid (Krynac X 146, Krynac X 160). When the principles explained are observed, vulcanisates based on XNBR grades containing 7% carboxylic acid (Krynac X 750) also offer advantages. In addition to vulcanisates containing carbon black, compounds containing silica are also discussed and it is shown that, in this case, the additional use of silanes is indispensable for effective vulcanisation.

INTRODUCTION

The market for carboxylated nitrile rubber (XNBR), a terpolymer of butadiene, acrylonitrile and an unsaturated carboxylic acid, in industrial rubber products is traditionally based in the sectors of industrial drive technology, materials handling, the textile industry, seals in the automotive and industrial sectors and other speciality applications.

Its special properties, which include:
- very low abrasion and good wear resistance
- outstanding vulcanisate properties in terms of strength and modulus
- excellent bonding to polar substrates as a result of a possible reaction between substrate and carboxylic acid, and
- the hydrophilic properties, which are also due to the carboxylic acid,

have, for many years, covered important areas of application for which XNBR is indispensable.

On the other hand, however, further diversification has been restricted not only by the somewhat higher price of the raw materials and the “nerve” of the polymer resulting from intermolecular hydrogen bond interactions, but also, until now, by the crosslinking system of zinc oxide and a conventional sulfur system, which is essential for the property profile of the vulcanisates.

The metal oxide and sulfur crosslinking agents together enable curing to take place with the incorporation of carboxylic acid and double bond into the polymer chain, with the consequences that processing safety often fails to meet the requirements of modern process control, that the handling of a curable compound may be difficult and involve additional costs and that the low thermal stability – in terms of compression set properties and heat ageing resistance – is significantly lower than for nitrile rubber, particularly at high temperatures, because of the zinc oxide.

This report presents, for the first time in this depth, a crosslinking method using no zinc oxide – an
environmental toxin [1] – which is characterised by stable, covalent crosslinking bridges and is largely able to compensate for the above disadvantages of XNBR.

STATE OF THE ART IN CURING SYSTEMS FOR XNBR

Since the basic work by H.P. Brown 1957 [2], crosslinking with zinc oxide and sulfur has determined XNBR technology. He and subsequent authors [3] explained that a reaction [4], later recognised as “cluster-type” crosslinking of the dispersed zinc oxide particles with the carboxyl group, is the key factor in many of the excellent properties mentioned but also leads to the above problems.

Some improvement in terms of processing is made possible by using zinc peroxide instead of zinc oxide [5]. However, owing to the handling and availability problems associated with this product and the weaknesses that still exist with regard to vulcanisate properties, this possibility does not offer a general solution. Efforts should therefore be made to find alternative, metal oxide-free solutions.

There have been a number of proposals in the past [6], for example crosslinking systems based on diamines, diepoxides (diglycidyl ethers of bisphenol A) as used in the production of epoxy resins, carbodiimides, blocked isocyanates and thiophosphoryl polysulfides [7]. However, all of these methods are unilateral in their action, reacting either with the carboxyl group or with the double bond, and since they display various kinds of disadvantages, they have so far failed to achieve any great industrial significance. At best, peroxides have gained limited success in 2-component technology [8, 9].

The following sections will show that α-alkyl phenol resols, as used in the resol crosslinking of butyl rubbers and in the production of thermoplastic elastomers, represent a dual crosslinking system for XNBR which offers a series of technical and cost advantages and can, in this sense, be described as universal. In this paper, the term “resol crosslinking” has been preferred over the usual term of “resin crosslinking” since it correctly addresses the chemical nature of the crosslinking agent.

RESOL CROSSLINKING – DIFFERENTIATION FROM CROSSLINKING WITH ZINC OXIDE AND SULFUR

The basic work by Werner Hofmann on “Vulkanisation und Vulkanisationshilfsmittel” [Vulcanisation and vulcanising auxiliaries], 1965 edition [10], already mentions resin crosslinking for carboxylated nitrile rubbers. The author is not aware of any later developments aiming to introduce the method into subsequent industrial practice.

The resins currently under consideration are resols based on α-alkyl phenols with the general structure shown in Figure 1.

The commercial products contain approx. 5 – 15% hydroxymethylene groups. Some are modified with bromine, having a bromine content of approx. 4 – 5%. The products are highly compatible with NBR and XNBR and, since their melting or softening point is relatively low, can readily be dispersed homogeneously. Products without halogens require halogen-containing additives as activators, which should not be derivatives of polyvalent metals. Bromine-modified resols are sufficiently reactive already but are significantly more expensive because of the halogen modification. The resins used in this paper are listed in Table 1.

Resols can react with the carboxyl groups of the XNBR polymer to form esters, with the hydrogen atoms in α-position to the nitrile group to form ethers and with the double bonds to form oxacyclohexane derivatives [11]. Since the resins are at least bifunctional, covalent crosslinking bridges are formed which are thermally and oxidatively more stable than ZnO clusters and sulfur bridges.

Like crosslinking with zinc oxide/sulfur, resol crosslinking is also dual in nature. For the best crosslinking...
structures, the reactive components in the polymer chain, i.e. double bonds and carboxyl groups, and the secondary components of the polymer resulting from its production have to be balanced.

If this factor is taken into account, better stability exists from the start with resol crosslinking, e.g. in terms of the compression set at higher temperatures, compared with conventional crosslinking. Since thermal/oxidative stability is substantially determined by the double bonds in the polymer chain, this is at approximately the same level as that of conventional nitrile rubber vulcanisates.

This brief outline suggests a close interrelation between the type and composition of the polymer and the type of resol. Reference is made to section 4, which deals with this subject.

**Compound composition**

At this point, however, further information relating to the compound composition is required, in so far as it relates to experimental studies up to the present (cf. also [12]).

**Metal oxides**

Metal oxides have a detrimental effect. Zinc oxides are unnecessary. Tin(II) chloride, a conventional activator for resol crosslinking, cannot be used as it reacts with the carboxyl group in a similar way to zinc oxide.

**Halogen-containing compounds**

Halogens have an accelerating effect. In the case of relatively high proportions of halogen-containing components – such as flame retardant plasticisers – there is a risk of premature curing. However, small quantities may be suitable as activators for halogen-free resols. The addition of 5 – 10 phr polychloroprene is also conventional in this context.

**Anti-ageing agents**

Resols are deactivated by amines. Anti-ageing agents such as TMQ or MMBI are therefore a particular problem. Diphenylamine derivatives are possible if slight reductions in properties can be accepted. On the other hand, phenolic anti-ageing agents, such as bisphenols, are effective at levels of about 4 phr without any negative effect on crosslinking.

**Epoxides**

Epoxides react with phenols to form phenyl ether derivatives. Epoxide-containing compounds should be avoided as plasticisers (epoxidised soybean oil) or as a component of the side chain in silanes (cf. section 7).

**Fillers**

Silicas interfere with the interaction between resol and polymer and are therefore apparently of only limited suitability as fillers. The solution to this problem is reported in detail in section 7.

Taking the above information into account, basic compounds for carbon black-containing and coloured articles can be recommended as shown in Table 2.

Compared with conventional crosslinking with zinc oxides and sulfur-based crosslinking systems, resol crosslinking offers a series of advantages in terms of process costs and the essential properties of rubber articles made therefrom, which – as far as has been demonstrated at present – are compiled below in comparison with zinc oxide/sulfur.

### Process engineering

Mainly owing to the lack of zinc oxide, compound viscosity is reduced by up to 30% with an otherwise identical composition. This leads to a significant improvement in the compound's flow properties, by up to 100% as determined by rheovulcameter testing at 180°C. The sheets are smoother, while die swell and calender shrinkage are lower. The compounds are very likely to be highly suitable for injection-moulded articles. Extrusion, e.g. for hoses and processing on a calender/roller head for films and fabric coating, is improved.

### Table 2. Typical compounds for resol crosslinking in phr

<table>
<thead>
<tr>
<th></th>
<th>Carbon black-containing grade</th>
<th>Coloured grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krynac X*</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vulkanox BKF*</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Carbon black N 550</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>Carbon black N 772</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>Vulkasil S*</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Silane TESP</td>
<td>-</td>
<td>2 – 6</td>
</tr>
<tr>
<td>Titanium dioxide</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Aflux 25*</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Mesamoll*</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Resol</td>
<td>6 – 13</td>
<td>6 – 13</td>
</tr>
<tr>
<td>Bayiren 210* (optional)</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Specific gravity / g/cm³ approx. 1.198 approx. 1.147

*Trade name of Lanxess AG
TESP is bis[triethoxysilylpropyl]tetratsulfane (Si 69)
This advance comprises a substantial cost benefit, which can be exploited by any processor, depending on conditions.

**Compound logistics**

Compounds with zinc oxide as a curing agent often have a very limited shelf life. Particular care is needed where zinc peroxide is used to improve this.

Compounds crosslinked with resol generally have a significantly improved shelf life.

Conditions such as curing tests after 3 days’ storage at 40°C, corresponding to a shelf life of about 10 days at room temperature, can be met subject to careful compounding. In critical cases, this can lead to improved production planning and a reduction in the quantity of compounds having to be rejected because the recommended storage time has been exceeded.

**Physical criteria**

**Stress-strain properties**

High moduli with a predetermined hardness are among the essential properties of elastomers based on carboxylated nitrile rubbers. These properties are achieved firstly only in polymers with a high acid content of e.g. 7% and secondly with the consequence that the inevitable “cluster-type” crosslinking of zinc oxide with the carboxyl group displays low resistance to stress relaxation. For this reason, vulcanisates crosslinked with zinc oxide/sulfur are used as a sealing material to meet current industrial demands only in special cases.

Carboxylated rubbers crosslinked with resol are fully active even with carboxylic acid contents of only 1% and enable vulcanisates to be produced with compression sets of about 35% at 340 h/100°C long-term loading. This value corresponds to about half of the value that can be achieved with a vulcanisate crosslinked with zinc oxide/sulfur.

**Low-temperature swelling compromise**

Crosslinking with the zinc oxide/sulfur combination only enables the desired vulcanisate properties to be achieved in polymers that have a relatively high acid content. In order to obtain adequate low-temperature properties that still match those of a copolymer with 33% acrylonitrile, an acrylonitrile content of approx. 28% is specified here. This results in higher swell compared with NBR grades with 33% acrylonitrile. Resol crosslinking permits a better compromise, since a property profile typical of XNBR is achieved in terpolymers with only 1% carboxylic acid. The acrylonitrile content can therefore be adjusted to 33%, so that excellent swell properties are achieved while maintaining a satisfactory glass transition temperature.

**INTERACTION OF RESOL WITH XNBR POLYMER**

With NBR copolymers as well as HNBR, a good level of crosslinking can be achieved by resol crosslinking activated with SnCl₂ [13]. However, mainly owing to the reaction with the carboxyl group in XNBR terpolymers caused by tin chloride, this form of activation is unsuitable here.

As shown in Figure 2 using Krynac X 146 as an example, compounds are crosslinked with SP 1055 with no additional activation. Compared with conventional zinc oxide/sulfur crosslinking, curing is slower but achieves a higher torque under the conditions given.

Experience has shown that the curing properties are substantially determined not only by the chemical structure of the resol – as expected – but also by the composition and production technology of the polymer component. Within the framework of this project, therefore, all the possibilities offered by the Krynac X range were exploited. Particular attention is paid to Krynac X 750 and Krynac X 740 with 7% carboxylic acid monomer and Krynac X 146 with 1% carboxylic acid monomer. Krynac X 160 is comparable to Krynac X 146 but with a higher Mooney viscosity.

For the unmodified resol SP 1045, the following sequence was determined for the Krynac X grades in terms of systematically increasing reactivity, based on rheometer curves (Figure 3):

Perbunan < X 146 < X 750 < X 740
This sequence runs parallel to the carboxylic acid content in the polymer, assuming additional activation in the case of X 740. Tests using gumstock compounds show that, even without adding CR, X 740 is self-activated to such an extent that the product should be regarded as curing too rapidly for many applications. Krynac X 750 is therefore the better option for the combination of SP 1045 plus CR.

The results of tests with SP 1055, the bromine-modified phenol, differ from the results with SP 1045 (Figure 4). A very high curing rate is observed here for the XNBR grades with 7% carboxylic acid, i.e. X 750 and X 740, with only minor differences between the two. Krynac X 146 is more suitable and represents a good compromise between satisfactory curing rate and good processing safety. The crosslinking efficiency is determined directly by the amount of resin added, up to at least 15 phr, with a corresponding slight reduction in scorch safety. In addition, Figure 5 shows that for Krynac X 146 (1% carboxylic acid), the crosslinking efficiency is improved over the comparison compound cured with zinc oxide and sulfur with just 5 phr resol, while the polymer with 7% carboxylic acid requires over 7 phr resol to achieve a better level than with zinc oxide/sulfur.

RHEOLOGICAL PROPERTIES

There are obvious reasons to assume that compounds with resol crosslinking are more easily processed than compounds with conventional zinc oxide/sulfur crosslinking, as demonstrated by the following facts:
- There is no possibility of any kind of interaction between zinc oxide and the polymer.
- The crosslinker resins are soft or molten under conventional processing conditions and act as processing aids.

According to Figure 6, the presumed effect is substantial. For the carboxylated grades, at least, it is almost 30 Mooney units (MU). The plasticising effect of the resins

Figure 3. MDR rheometer curves for different XNBR polymers compared with NBR. Resol: SP 1045 (10 phr) activated with CR (Bayprene 210 – 5 phr); MDR rheometer: 170°C/60 min; NBR: Perbunan 3445 F

Figure 4. MDR rheometer curves for different XNBR polymers compared with NBR. Resol: SP 1055 (10 phr); MDR rheometer: 170°C/60 min; NBR: Perbunan 3445 F

Figure 5. Influence of resol SP 1055 content on crosslinking efficiency in Krynac X 146 and Krynac X 750; reference is compound of similar composition but with zinc oxide/sulfur; MDR rheometer: 170°C/60 min
appears to dominate, since the copolymer Perbunan also displays a lower viscosity.

Figure 6 also illustrates the fact that Krynac X 740 often fails to offer the necessary processing safety, since the viscosity increase shown in compounds with SP 1055 can be attributed to scorch.

Improvements can also be observed in compounds with precipitated silica. With Krynac X 750/SP 1045, for instance, the compound viscosity with resol crosslinking is 10 Mooney units lower than with zinc oxide/sulfur crosslinking.

As already mentioned, curable XNBR compounds with zinc oxide/sulfur have a very limited shelf life. Resol crosslinking improves the situation considerably and – depending, of course, on the overall composition of the compound – provides adequate safety in most cases.

In addition to the safety achieved by the shelf life, the improved flow properties represent significant technical progress for extrusion, calendering and injection moulding. One example of this is the investigation of mould filling in a rheovulcameter with a ramification mould at a mould temperature of e.g. 180°C. The vulcanisates produced in this way are documented in Figure 7, comparing resol-crosslinked Krynac X with sulfur-crosslinked Perbunan and sulfur-crosslinked Krynac X.

In the case of resol crosslinking, the mould filling process is comparable with corresponding NBR copolymers. It is determined predominantly by the compound viscosity. Based on this result, it appears to be possible to process resol-crosslinked XNBR compounds by injection moulding, in the same way as NBR compounds. The lower compound viscosity with resol crosslinking causes lower Mooney relaxation, which also opens up a cheaper processing window for these processes.

VULCANISATE PROPERTIES – CARBON BLACKS AS FILLERS

No specific interactions between carbon blacks as fillers and resols are known. The properties of vulcanisates are therefore determined overwhelmingly by the vulcanisation partners, i.e. the polymer and the crosslinking agent.

Hardness, tensile properties, particularly the modulus, abrasion resistance and compression set are among the most important properties of vulcanisates. These are shown in Figure 8 as a function of the amount of resin added, using Krynac X 146 (with 1% carboxylic acid) and Krynac X 750 (with 7% carboxylic acid) as parameters. The resol-crosslinked vulcanisates are compared with results for vulcanisates having zinc oxide/sulfur crosslinking in an otherwise identical composition.

The representation selected for Figure 8 contains the key to understanding the importance of resol crosslinking for XNBR. A comparison with zinc oxide/sulfur crosslinking shows the following:

For resol-crosslinked Krynac X 146, moduli are higher and compression sets lower than for the conventional crosslinking system. Resol crosslinking is therefore considerably more effective, according to the relationships derived from the rheometer curves. When the crosslinking agent is added in quantities within the range specified, only one product, Krynac X 146, is capable of covering the entire existing property profile from all available XNBR grades and, in the case of the compression set, even exceeding it significantly. Krynac X 146 and the corresponding Krynac X 160 are therefore no longer speciality products but have become universal grades within the XNBR series.

Products with 7% carboxylic acid, on the other hand, become less important with resol crosslinking, partly because, like Krynac X 740, they are too active and
partly because, as illustrated in Figure 8 for Krynac X 750, the properties existing with zinc oxide/sulfur are achieved only with relatively high additions of resol.

The abrasion resistance, which is so essential for XNBR, is barely affected by the resols and remains at a good level.

The tensile test merits further attention. Reference is made to Figure 9. All of the vulcanisates are strongly affected by the resol content. The modulus varies systematically with this content. The strength remains at a high level, as expected, while the elongation at break is reduced considerably as the resol content increases.

Comparing the acrylonitrile contents of the XNBR grades with 1% and 7% carboxylic acid, i.e. 33% and 28%, it may be assumed as a hypothesis that the nitrile group (or its immediate vicinity) contributes significantly to crosslinking. This assumption is supported by indications from tests with hydrogenated nitrile rubber [10].

VULCANISATE PROPERTIES – SILICAS AS FILLERS

With silica as a filler, the case is more complex since, in addition to the desired interaction of resol with carboxylic acid, the undesirable interaction of resol with silica and...
possibly also the interaction of silica with the polymer must also be taken into account (Figure 10). In the case of resol crosslinking, the interaction between the resol component and silica has such a significant detrimental effect on the crosslinking reaction that only a slow curing reaction is generally observed, which is industrially unviable. This interaction is suppressed by the hydrophobic treatment of the silica with suitable functionalised alkoxysilanes, and “reasonable” rheometer curves are obtained (Figure 11/1). The hydrophobising step can take place by reactive mixing in internal mixers or by using silane-modified silicas. Suitable silanes include those with alkyl, sulfur or vinyl modification. Amino- or epoxy-modified grades, on the other hand, have a negative effect on curing, as expected (Figure 11).

In this system, silane and resol each form additives with effects on compound and vulcanisate properties which in some cases complement one another, in some cases counteract one another and in other cases are independent of one another. Determination of these effects in detail was based on a statistically planned series of tests (JMP software [14]) for a compound based on Krynac X 146 with 40 phr Vulkasil S, the addition of TESP being varied between 0 and 6 phr and of SP 1055 between 4 and 13 phr. The results of this test are reproduced in simplified form in Table 3.

According to these results, high silane contents are needed for articles with high wear resistance. Independently of this, compression set and modulus — and therefore elongation at break — can be adjusted by the resol content, as illustrated in Figure 12. This decoupling is surprising, particularly as the abrasion test should be sensitive to changes in modulus, based on the method.

Table 3. Influences of silane and resol on essential compound and vulcanisate properties

<table>
<thead>
<tr>
<th></th>
<th>Increasing content of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Silane</td>
</tr>
<tr>
<td>Compound viscosity</td>
<td>better*</td>
</tr>
<tr>
<td>Scorch time</td>
<td>better**</td>
</tr>
<tr>
<td>Modulus</td>
<td>almost no effect</td>
</tr>
<tr>
<td>Abrasion resistance</td>
<td>better</td>
</tr>
<tr>
<td>Compression set</td>
<td>almost no effect</td>
</tr>
</tbody>
</table>

* complex, non-linear relationship
** significant delay with silane, not effective with SP 1055 content > 8 phr

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Figure 10. Possible interactions in a curable mixture with silica as filler

Figure 11. MDR rheometer curves at 170°C — influence of functionalised alkoxysilanes on resol (SP 1055) curing of compounds based on Krynac X 750 with precipitated silica as filler

1. Comparison of carbon black with silica
   a. Compound with carbon black
   b. Compound with precipitated silica
2. Effect of functionalised silanes after grafting in internal mixer
   a. TESP = bis(3-triethoxysilylpropyl)tetrasulfane [Si 69]
   b. VTEO = vinyl silane
   c. OCTEO = octyl silane
   d. GYEO = silane with epoxy group
   e. AMEO = silane with amino group
3. a. TESP-modified active precipitated silica
   b. alkyltriethoxysilane-modified fumed silica
Table 4. Overview of typical properties for a vulcanisate with a combination of precipitated silica/TESP/SP 1055

<table>
<thead>
<tr>
<th>Basic polymer Krynac X</th>
<th>750</th>
<th>146</th>
<th>750</th>
<th>146</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler</td>
<td></td>
<td></td>
<td>Precipitated silica (30 phr)</td>
<td></td>
</tr>
<tr>
<td>Silane TESP content / phr</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Resol</td>
<td></td>
<td>SP 1055 (10 phr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compound viscosity M(1+4') 100°C / MU</td>
<td>70</td>
<td>55</td>
<td>69</td>
<td>67</td>
</tr>
<tr>
<td>Hardness / Shore A</td>
<td>57</td>
<td>68</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Strength / MPa</td>
<td>24.6</td>
<td>19.4</td>
<td>17.2</td>
<td>15.5</td>
</tr>
<tr>
<td>Elongation at break / %</td>
<td>565</td>
<td>536</td>
<td>395</td>
<td>345</td>
</tr>
<tr>
<td>Modulus (50% elongation) / MPa</td>
<td>1.3</td>
<td>1.3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Abrasion / mm³</td>
<td>133</td>
<td>136</td>
<td>58</td>
<td>59</td>
</tr>
<tr>
<td>Compression set (168 h/100°C) / %</td>
<td>51</td>
<td>38</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 12. Influence of silane and resol content on abrasion and modulus in vulcanisates based on Krynac X 146 with precipitated silica as filler (graphs based on calculated values)

A typical property profile for coloured vulcanisates is shown in Table 4 from a series of tests. Here again, Krynac X 146 is the polymer that leads to the best overall result, with particular reference to abrasion and compression set.

CONCLUSIONS

Resol crosslinking, the versatility of which has been demonstrated using the example of Krynac X carboxylated nitrile rubbers, should lead to improvements in the existing areas of application and open up new opportunities for the speciality elastomer XNBR, which is otherwise restricted in its applications by limitations in terms of its processing properties and important vulcanisate characteristics. The following can be envisaged:

In the seals sector, new opportunities will be opened up with vulcanisates based on Krynac X 146 as a result of improved processes (injection moulding) and improved properties (sealing force). These also include elastomer/thermoplastic composites, especially since chemical reactions between e.g. polyamide and resol may be of additional significance.

Use for wear-resistant industrial rubber articles in extreme hardness ranges, where the advantage of resol crosslinking lies in the improved processing properties due to lower Mooney viscosity, and for low-hardness articles where it lies in the high abrasion resistances that can be obtained by adjusting the silane content, for instance in coloured vulcanisates.

In rollers – including so-called “drafting rolls” – significant progress can be achieved in terms of dynamic resistance by incorporating silane technology. An excellent compression set can be obtained by adding appropriate quantities of resol.

N.B.: For parts of this report, a patent application has been lodged (filed on 21.1.2013 at the European Patent Office, Munich).

REFERENCES


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