Powder rubber - a new generation of raw materials for easier processing in the rubber industry

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Starting with the individual raw materials, the following paper describes the development and production of free-flowing rubber/filler composite systems with the emphasis on E-SBR/carbon black or NR/carbon black. There will also be a discussion of handling and applications in present and possibly future processes in the rubber industry.

The objective of this work is to offer users a free-flowing, non-tacky, highly dispersive form of rubber and filler enabling them to extend their production processes in a wide variety of ways compared to current technology and, if appropriate, completely to reorganise them.

1. INTRODUCTION

For several years, virtually all renowned tyre manufacturers have been working on the development of new procedures for simpler and, obviously, cheaper tyre production [1-3]. According to our current level of knowledge and the published material, these new processes generally involve a departure from the present-day discontinuous machines, which have remained virtually unchanged for many years, in favour of smaller, more flexible units with the emphasis on continuous production processes.

Current technology is based on the discontinuous mixing of rubber in bale form with granulated (prilled) fillers. During this, the granulated fillers first have to be broken down, which requires a large amount of energy to facilitate the wetting of the surface by the polymer. The heavy, inflexible mixing units used for this, such as internal mixers and rolls, have been suitably adapted and optimised for this type of raw material and processing technology over the years – in fact they require them.

However, on the other hand, it is the unanimous opinion of experts that the development and introduction of new continuous mixing processes [4-6], which have been state-of-the-art technology in the rubber industry for many years, require free-flowing, powdery rubber/fillers [7]. One of the most promising approaches towards achieving a significant progress in this field, which was taken up again approximately 2 years ago [5, 6, 8] is definitely the development of rubber/filler batches in powdery form – generally known as powder rubber. The renewed interest in this technology goes hand in hand with the increasing interest of the rubber industry, particularly the tyre industry, in developing new techniques for the production of tyres.

The following work is a report on the status of development concerning E-SBR/carbon black or NR/carbon black systems.

2. OBJECTIVE AND PROCEDURE

The development and production of powdery, free-flowing powder rubber products may assist the introduction of continuous mixing processes in the rubber industry in the medium to long term. Work of this kind is currently being carried out in the Deutsche Institut für Kautschuktechnologie (DIK) in close co-operation with renowned machine building companies [9, 10].

However, powdery rubber/filler batches also have advantages over bale rubber technology for the discontinuous production processes in current use.

These relate both to the processes before the actual production of the mixture (e.g. storage, automatic metering and weighing all the components of the mixture) and to
the actual mixing process (e.g. reduced mixing time and mixing energy, homogeneity, dispersion and vulcanisation properties). Neither should we ignore the environmental aspects (e.g. polymer-bonded carbon black, fewer dust emissions) which are an additional benefit of powder rubber technology [8-10]

3. THE RAW MATERIAL CONCEPT

With E-SBR/carbon black and NR/carbon black systems, the starting material for the production of powder rubber is a aqueous latex emulsion. The processing stages required for the production of bale rubber such as coagulation, mechanical water separation and thermal drying and the compaction of the crumbs of rubber into bales and their packaging may be dispensed with. In the case of natural rubber, there is also no need to stabilise the material by smoking. This reduces damage to the environment and saves natural resources.

In the powder rubber process, fluffy carbon black is the form used for both E-SBR/carbon black and NR/carbon black. This means there is no need for all the high-energy and cost-intensive processes for the production of carbon black pearls such as those commonly used in the rubber industry.

The powder rubber process therefore represents the future finishing method for both rubber and fillers (Figure 1).

The raw materials used are determined primarily by the current circumstances and requirements of the rubber-processing industry. Therefore, types E-SBR 1500, 1712 and 1721 are mainly considered for E-SBR. When the last two types are in bale form, it is normal to add plasticiser oils (37.5 phr). The degree to which this is possible in the powder rubber process and the order of magnitude will be discussed in one of the later sections.

Although with E-SBR latex, it is relatively simple to obtain customised products (e.g. viscosity setting, styrene content) from various polymer manufacturers, natural rubber systems are much more complicated. There are two basic variants of this latex. Centrifuge latex is a 60% concentrated product which is nowadays mainly used for the production of internally-used products (such as medical gloves, condoms). Despite its advantages with regard to purity and shelf life, centrifuge latex cannot be used in the powder rubber process for reasons of cost.

Field latex is a more economical alternative. This is crude rubber milk obtained by tapping a rubber tree with a solids content of approximately 30%. As a natural product, this raw material has large quantities of foreign components, mainly salt, resins and proteins. This is one of the reasons why NR latex - particularly field latex, has to be protected against bacterial attack. It is usual to add ammonia (approximately 0.8%) or a combination of ammonia (approximately 0.25%) and ZnO and TMTD, the last two in quantities of approximately 0.1-0.2%. A suitable stabilisation system containing no volatile N-nitrosamine-forming additives has been developed for the use of field latex in the powder rubber process.

Natural rubber has a much higher molecular weight than synthetic types of rubber [11] and when stored this increases still further as a result of intermolecular condensation reactions. The resulting Mooney viscosity values measured in NR bales of approximately 90-110 Mooney points therefore often require a mechanical degradation process before the actual addition of the filler - this is performed on a roll or in an internal mixer. Normally, viscosities of around 70 are set. This may be achieved with or without the assistance of degradation agents [12]. In the former case, less time is required for the mastication process.

A mastication stage of this kind cannot be performed in the finished powder rubber which already contains the

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**Figure 1** Raw material concept for the production of carbon black-filled powder rubbers
entire amount of filler. However, as one of the objectives of powder rubber technology is to reduce mixing times and the number of mixing stages \([5, 8]\) and even to facilitate the introduction of continuous mixing processes \([9, 10]\), particular attention should be paid to the viscosity of the NR latex used in the powder rubber. With the material used at present in the powder rubber process, the use of special low-viscous lattices has made it possible to produce NR/carbon black powder rubber products which, provided the correct mixing sequence is used, result in low mixing viscosities even with short mixing times. Despite a high molecular weight of about 800,000, therefore, there is no need for the mastication process. This material may be used for single-stage mixing processes as found with continuous mixing. The high chain length in turn forms the basis for the subsequent excellent values. The table below shows the most important types of rubber currently used with success in the powder rubber process (Table 1).

<table>
<thead>
<tr>
<th>Table 1 Rubber emulsions for the production of powder rubber</th>
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<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Solids content</td>
</tr>
<tr>
<td>Viscosity ML 1 + 4</td>
</tr>
<tr>
<td>Minor constituents</td>
</tr>
<tr>
<td>Shelf life</td>
</tr>
<tr>
<td>Stirring stability</td>
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<td>Availability</td>
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As described, the carbon blacks for powder rubber are collected shortly after the furnace process and added to the powder rubber production process. In addition to dispensing with prilling and drying, fluffy carbon black has other procedural and applicational advantages. It has finer particles than wet-prilled carbon black and a narrower particle size distribution.

For the powder rubber product in the mixing process, this means that the filler is already at a smaller particle size stage and hence is pre-dispersed in the rubber matrix. The mixing time selected to achieve the final dispersion of the filler may then be correspondingly short. The use of fluffy carbon black is therefore an important precondition for single-stage continuous mixing processes. Another important difference between fluffy and wet-prilled carbon black is its purity. Experience has found the grit content to be low and it drops still further during the powder rubber process. This should have a beneficial effect when used to produce thin-walled extrusion products (such as profiles), where the grit content of the filler is often responsible for a high scrap rate. This should presumably reduce the need for countermeasures such as straining rubber mixes.

4. PRODUCTION

In both systems, the first stage in the powder rubber process is the separate production of a stable latex emulsion and a homogeneous filler suspension in water. Even when dealing with the latex, attention should be paid to the special properties of the two types. Although E-SBR latex behaves relatively well as far as its stirring stability is concerned, special precautions must be taken with NR latex to prevent the premature uncontrollable precipitation of the rubber. This is done by the inclusion of additives and auxiliary agents shortly before recovery (Figure 2).

![Figure 2 Production of powder rubber from aqueous rubber emulsions](image_url)
The powder rubber is then produced by the joint precipitation of both components. Either Brønsted or Lewis acid may be used as the precipitating agent. The production parameters are adjusted to enable both types to be produced in one unit. The actual method of precipitation, however, is in different for the two systems and once again takes into account the different properties and behaviour of the two types of latex (precipitation behaviour) and the different requirements for the finished powder rubber product. Here, we should mention the tackiness of the products, which is much less pronounced in E-SBR than it is in NR. Other adjustments are necessary due to the fact that NR products usually have lower filler contents than those based on E-SBR.

The powder rubber process is a procedure in which the coagulating latex sheaths filler particles without any uncontrolled granulation occurring, i.e. there are no unwanted lumps in the products. In addition, the selective addition of a second filler fraction provides each grain of powder rubber with an effective lining, a measure which later in the finished product makes a decisive contribution to the desired flowability of the material. The subsequent solid/liquid separation removes the majority of the process water mechanically and finally the product is dried thermally to achieve a moisture content of approximately 1%. During the entire production process, the product must be treated gently. During the drying, the powder should be continuously agitated to prevent lumps from forming.

5. PRODUCTS

Obviously, when introducing a new generation of raw materials consideration should be paid at an early stage, and here the assistance of the users should be requested, to how long in the future the types of rubber and carbon black produced will actually be required to meet product requirements. A certain limitation of the range of raw materials should help to simplify storage at the user’s premises and once again help to reduce costs.

With E-SBR, the choice will definitely be determined by the main types of solid rubber used at present. These are E-SBR 1500 and E-SBR 1712. For car tyre treads, the main field of application for E-SBR, the most commonly used carbon blacks are N234 and N339.

As far as the filler content is concerned, we imagine that two types of filler content will be offered for both E-SBR and carbon black as the upper and lower limits in the rubber-relevant range. This would enable compounders to set all the filler contents between these limits by blending two products. A similar procedure is conceivable for NR products as well. The types of carbon black and filler contents will once again be determined by the current requirements levied on rubber articles.

As in bale technology, plasticiser oils may also be added during the production of powder rubber. In principle, it should be possible to incorporate the same quantities of oil as those usually used in bales (37.5 phr). However, in order not to have an over-negative impact on the suitability for storage in silos, it has been found to be advantageous to reduce the quantity of oil to 15-25 phr and make it dependent upon the carbon black content. The user should add the missing oil directly in the kneader, which is no problem due to the high absorbency of the powder rubber.

6. FORM SUPPLIED, TACKINESS, TRANSPORTATION, STORAGE

Powder rubber is a free-flowing, rubber/filler compound in which the filler is already incorporated in the rubber matrix in a pre-dispersed form. The particle size and its distribution may be set within a wide range by varying the production parameters, at least in the filler content range relevant to rubber technology. A narrow particle size distribution with an average particle diameter of 600-800 µm has been found to be suitable with regard to dust content, oil absorption and the dispersion of the material, particularly in a continuous extruder mixing process. A narrow particle distribution and a round grain shape also have a positive impact on suitability for storage in silos.

In the current procedure, the tackiness of the products may be extremely positively influenced by the introduction of a filler layer mechanically anchored to the rubber phase. The splitting layer consists of the filler already present in the product. This excludes the possibility of unwanted foreign matter, which could subsequently have a negative influence on the rubber technology (Figures 3-5).

An X-ray electron microscope photograph clearly shows this layer, which is 10-20 µm thick. It is mechanically anchored to the grain and is even able to withstand the...
mechanical stresses that may occur in the rubber industry during pneumatic transportation. More extensive investigations under practical conditions (fluid lift and fluid shear) confirm these observations. Even under the harsh conditions of the fluid lift process, no significant increase in the product’s dust content was determined.

Particularly with powder rubbers based on NR/carbon black but also with powder rubbers based on E-SBR 1712 (1721)/carbon black, in which the majority of the plasticiser is incorporated in the product, further measures are necessary to reduce tackiness to maintain suitability for storage in silos over lengthy periods. Subsequent coating with ZnO (1 phr), a chemical contained in virtually all rubber mixes as a vulcanisation activator, has been found to be beneficial. Users should reduce the amount of ZnO they themselves add to the mixture in accordance with the quantity used.

7. HOMOGENEITY AND PRODUCT CONSTRUCTION

The current gentle powder rubber production process guarantees an extremely homogeneous distribution of filler and rubber (Figure 6). The desired ratio of the two components is ideally established in each powder rubber grain during precipitation. As there is no severe mechanical stress during the processing, once set, this relationship is retained. There are virtually no fluctuations in filler on the one hand and the rubber on the other – and hence no fluctuations in the filler content.

A TEM photograph of a mixture of E-SBR and carbon black in water before the coagulation of the latex clearly reveals that the latex droplets interact with the carbon black particles on their surface.

Due to the size of the latex droplets and the fact that the structure is filled with water, the latex is probably not able to penetrate the carbon black structure. A mechanical process, such as that which occurs in internal mixers and causes the polymer to penetrate the filler structure, does not take place during the production of powder rubber.

However, this means that the filler structure in the powder structure remains open after drying, i.e. it

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**Figure 4** Section through a grain

**Figure 5** Outer zone

**Figure 6** Distribution of rubber and carbon black in water and in powder rubber
8. POWDER RUBBER IN A DISCONTINUOUS MIXING PROCESS

The use of powder rubber involves some important differences from conventional production processes, even with kneader mixing. For example, there is no need for the preliminary weighing and comminution. Instead of storing the fillers in silos, these containers are now used for the powder rubber. In this way, all the components of the mixture may be fed into the mixing unit by means of an automatic weighing and metering system. There is no need to handle loose carbon black and dust emissions are reduced.

In addition to the usual direct processing of the products in internal mixers and on rolls, it is also possible to mix all the components of the mixture with the powder rubber in a powder mixer first and then perform the plasticising stage with the mixture containing all the ingredients as usual in kneader or on a roll. In continuous mixing processes, a premix of this kind may be fed to a compounding extruder by means of a metering unit.

8.1 Metering powder rubber

Investigations into rubber technology have found that powder rubber with the same filler content as standard mixtures has much higher reinforcing properties. This is evident in particular from the higher modulus of elasticity of 300% and the greater hardness and mixing viscosity.

At the current level of development, two effects are responsible for this:

- **The fluffy effect**
  Higher surface activity of the fluffy compared to wet-prilled carbon black
- **The powder rubber effect**
  Higher filler structure in rubber due to the structure-stabilising effect of the penetrating polymer chains.

These assumptions are supported by the determination of the bound rubber content. In powder rubber, this is always higher than it is in the comparable conventionally mixed standard material.

If necessary and desirable, measures can be taken to counteract these two effects:

- **The first possibility is to reduce the filler content.** If a standard E-SBR product has 80 phr N234, it has been found that an adjustment to 76 phr of N234 is suitable for the equivalent powder rubber. If, as intended, the user stores products with both a high filler content and a low filler content, he can simply blend these two products to establish his desired formulation in each individual case.

- **The second possibility for compensating the two effects described above is to increase the amount of plasticiser oil added.** This means that with the same filler content as the standard material, more oil can be added to powder rubber. This reduces the cost of attaining the required applicational properties.

8.2 Mixing procedure

The fact that the filler is already incorporated in the rubber matrix in the case of powder rubber shortens the mixing process in kneaders or on rolls to a brief plasticising and dispersion process. This saves the time that would otherwise be required for the incorporation of the filler. At the same time, the use of fluffy carbon black entails the use of a form of filler which is characterised by extremely fine particles and hence encourages dispersion [6].

**Table 2** shows the results of an investigation into mixing technology (E-SBR/N234) on a 45 L kneader.

For the standard material, a two-stage mixing procedure based on bale rubber and carbon black filler was selected. The total mixing time was 2.5 minutes: 1.5 minutes for the preliminary stage and 1 min for the finished stage. The kneader filler content in the first stage was increased by 10-15% for powder rubber to ensure that kneader blades had a good grip. The addition of the plasticiser (30 phr) took place in a stage of the mixing sequence in which the virtually all the powder rubber was still in powder form. This enables use to be made of the high suction force of the carbon black separating layer for the problem-free absorption of the oil.

This series of investigations succeeded in reducing the already very short mixing times for the standard material by about 45-50%. This resulted in an energy saving of up to 60% and an increase in capacity of 45-50%. The latter was due to the higher filler content and the shorter mixing time for the powder rubber product.

The dispersion properties of the powder rubber mixture are in all cases much better than those of standard material, or to put it in other words: to achieve the degree of dispersion of powder rubber mixtures, the standard material has to be mixed for much longer than occurred in this series of experiments. Similar investigations on the
NR/carbon black powder rubber system produced similar results. For example, the entire mastication period required for natural rubber is dispensed with. They also achieved further savings in the mixing time of approximately 50% with excellent dispersion values. The savings in mixing energy are just as significant.

As NR mixtures are usually mixed for much longer than E-SBR compounds, the absolute savings in the first case are naturally much higher.

Particularly in the case of the NR/carbon black system, it has been found to be advantageous to add antioxidants, particularly from the N-p-phenylene diamine class, at a later stage in the mixing sequence. Otherwise, the drop in viscosity of the NR rubber may be impeded.

8.3 Application properties

Table 3 is an overview of common laboratory data for a carbon black-filled powder rubber mixture based on NR/N234 compared to those for equivalent conventionally produced standard mixtures (filler content 50 phr). To compensate the fluffy effect and powder rubber effect, the filler content in powder rubber was reduced by 3 phr to 47 phr.

The composition of the mixtures corresponded to a truck tyre tread mixture with the usual content of activators, antioxidants and accelerators. The vulcanisation temperature was 150 °C. As well as dispensing with the mastication stage, the mixing time was reduced by about half (1 stage) for the powder rubber mixture. The antioxidant was only added shortly before the end of the first mixing stage, which, meant that, despite the reduced mixing time, the viscosity of the powder rubber mixture was approximately the same as the standard mixture. After correcting the filler content, the static and dynamic values of the powder rubber mixtures corresponded approximately to those of the standard mixture, but with a much shorter mixing time.

9. POWDER RUBBER IN A CONTINUOUS MIXING PROCESS

Continuous compounding extruder processes, the introduction of which has been repeatedly discussed for many years in the rubber industry, require a free-flowing form of rubber for automatic metering and feeding the mixer.

Unlike with internal mixers, the dwell time of the goods in the extruder is extremely short. In addition, the mixing process always takes place in one stage. In order to achieve good product qualities despite these short mechanical stresses on the mixture (dispersion), it is advantageous to be able to use a rubber/filler mixture with a high initial filler dispersion and good phase linking.
Powder rubber meets both requirements to a high degree and is hence an option for the development and introduction of continuous production processes.

9.1 Requirements for mixers

From the very start of the development of powder rubber, in addition to the advantageous use of these products in the present-day batch process, the objective was also to be able to use them in continuously operational mixers. Therefore, it appeared obvious to concentrate at first on the continuously operating devices that have been used successfully for a long time in the rubber industry – taking into account the fact that the highly viscous vulcanised rubber medium would levy different requirements on the design of the equipment than comparatively low-viscous polymer melts.

Figure 7 shows three different types of extruder which are currently the subject of investigations into continuous mixing with powder rubber. As is the norm, every different device has advantages and drawbacks to be exploited and rectified individually in intensive investigations.

Regardless of the individual extruder concepts, according to the current status of investigations, the following requirements should be levied on the equipment for the continuous mixing of rubber mixtures:

- high torque
- good cooling

9.2 Screw elements, screw configuration

The commonly used screw elements today may be divided into three classes:

The function of mixing elements with a dispersive action corresponds to that of the kneading blades in an internal mixer. They introduce high mechanical forces into the mixture and by doing so break up the filler agglomerates. In this way, they have a decisive influence on the dispersion, and hence the quality, of a rubber mixture. Their drawback is the fact that they heat up the mixture which usually means that it is not possible to add the temperature-sensitive crosslinking elements before exposure to these elements. Figure 8 shows two of the most common elements of this type.

Mixing elements with a distributive action are used to incorporate mix components, such as plasticisers and crosslinking chemicals and to deaerate the mixture. Their shear forces are low, and hence the amount of energy imparted is low so there is little heat build-up. Figure 9 shows two elements of this type; a polygon profile (left) and a sprocket block (right).

The third group comprises purely conveying screw elements. These are used to transport the mixed materials within the extruder. Once again, different geometries are used (Figure 10). Figure 11 shows a screw configuration using the above-mentioned screw elements permitting dispersion levels of way over 96% for both E-SBR/carbon black and NR/carbon black and in a second screw section with suitable cooling even permits the addition of
crosslinking chemicals. However, one unsatisfactory point is the output rate, which, in accordance with the objective of the production of curable rubber mixture in one stage, is at present 30-40% of the rated capacity of the extruder. A new generation of extruders which will be available in the near future with new screw elements optimised for mixing rubber should result in a significant improvement to the output rate.

Regardless of any other optimisation measures, we are already in a position to make the following basic statements regarding screw geometry and screw configuration for rubber processing:

- to achieve dispersion degrees of > 96%, it is necessary to use at least two mixing elements with a dispersive action
- preference should be given to the installation of conveying or neutral screw elements in order to avoid any unnecessary heat build-up
- wide inter-screw clearance in the elements facilitates material flow into the shear area
- wide kneading blocks encourage dispersion.

9.3 Material feed, metering, cooling, discharge

In principal, obviously all the mixing ingredients may be fed to the extruder by means of suitable weighing and metering equipment, but due to the generally high number of individual components this may be difficult to achieve. In practice, therefore, it has been found to be preferable to produce a premix (premix 1 in Figure 11), comprising powder rubber(s) and mixing components with little thermal sensitivity, such as ZnO, stearic acid, wax, antioxidants, resins with the aid of a powder blender and to feed this premix to the extruder continuously via a metering device. The plasticiser should be fed in through a feed point close behind this. A surge-free monopump generating a continuous non-fluctuating flow of plasticiser has been found to be particularly suitable for this. Optimum absorption of the plasticiser is ensured if the powder rubber is still in powder form, i.e. in the conveying area before the first dispersive mixing element. The absorbent splitting layer surrounding every powder rubber grain is then able to absorb large amounts of plasticiser. At the same time, it is obviously necessary to guarantee that the oil is given enough time to diffuse into the powder rubber grain before exposure to the first dispersive mixing
element, otherwise the effectiveness of the dispersion would be reduced (the mixer contents slip through, low shear forces) resulting in poor mixing quality.

The conveying zone after the dispersive elements is used to cool the mixture and to deaerate it at atmospheric pressure or in slight vacuum. Provided there is good cooling – and this should be optimised – the crosslinking chemicals may be fed into the extruder in the form of a premix (accelerator, sulphur, and, in the case of NR mixtures also antioxidants such as 6 PPD, TMQ) at temperatures of 100-110 °C. The two distributive screw elements are then used to distribute the premix 2 chemicals without any excessive additional temperature build-up. Extruders do not seem suitable for the direct removal of semi-finished products (e.g. tread strips) due to the poor pumping action. Investigations have shown [9, 10] that the attachment of a mould results in a disproportionate increase in temperature. Therefore, it makes more sense to remove semi-finished products by means of a gear pump. In such a case, even the direct straining of rubber mixtures is conceivable.

9.4 Energy input, temperature build-up, mixing quality

The production of a rubber mixture in a compounding extruder in the conditions described in sections 9.1-9.3 results in degrees of dispersion of 96-99%. This means they are much higher than those for comparable powder rubber mixtures (approximately 92-95%) in internal mixers or even conventionally produced compounds, based on bale technology (~ 80%), as has been demonstrated in numerous investigations. In order to achieve degrees of dispersion such as this, an energy input of 0.15-0.2 kWh per kg of mixture is required. This level approximately corresponds to the quantity of energy for one mixing stage in a kneader. However, as the product of a mixture in a kneader generally requires a multi-stage mixing process, the saving on mixing energy may be significant depending upon the rubber/filler system. It could be as much as 50-70%.

Figure 12 shows a screw configuration for measuring the temperature changes in the material being mixed during the mixing process in the extruder using the example of a powder rubber product based on NR/N234 47 phr. The temperature is determined by means of temperature sensors inserted at specific intervals in the extruder’s cylinder wall.

Table 4 shows the temperatures measured at measuring points T1 and after passing through the cooling zone (barrels 6-8) at point T2 in relation to the screw speed (constant throughput 12 kg/h).

The results clearly show that, as expected, after the first return-conveying dispersive mixing element, the temperature increases with the speed. However, it has also been found that with good cooling, it is possible to achieve a clear reduction in the temperature of the mixture up to measuring point T2 – with a lengthy screw, this is when the crosslinking chemicals should be added – despite additional dispersive, but not return-conveying, screw elements.

If these observations are transferred to internal mixer technology, this means that the temperatures measured at T1 in an extruder are approximately at the same order of magnitude as those found during the production of a

<table>
<thead>
<tr>
<th>Speed rpm</th>
<th>T1 (°C)</th>
<th>T2 (°C)</th>
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<tr>
<td>120</td>
<td>116</td>
<td>95</td>
</tr>
<tr>
<td>160</td>
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<td>220</td>
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<td>99</td>
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<tr>
<td>280</td>
<td>149</td>
<td>100</td>
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Figure 12 Test screw for determining temperature development during mixing
basic mix in a kneader (approximately 140-150 °C), while the temperatures measured at T₂ correspond to the temperatures in kneaders which are usually set in internal mixers in the final mixing stage for the addition of crosslinking chemicals. Therefore, both important temperature ranges for the production of the mixture in extruders (approximately 150 °C and approximately 100 °C) may be started in one process stage and hence a complete curable rubber mixture may be produced in one stage. Another possible advantage is the fact that the mixture’s dwell time in the extruder is only a few seconds and the temperatures described act on the materials mixed for a much shorter time than they do in a discontinuous internal mixer process.

REFERENCES
1. Neue Reifen Zeitung, 12/99 and 01/00
2. European Rubber Journal, May 1996
3. Neue Reifen Zeitung 01/00, EJU Rubber Trends 2nd quarter ’97
4. E.T. Italiaander, Gummi Fasern Kunstst. 50 (1997) 456
8. U. Görl, M. Schmitt: Paper given at the conference of the ACS Rubber Division, Dallas Texas, USA, April 2000
10. R. Uphus, O. Skibba, R.H. Schuster, Paper given at the conference of the ACS Rubber Division, Dallas Texas, USA, April 2000

(No date given)