10. Summary

The production of compounds represents the first and most important step in the production process of an elastomer component. Compounds are traditionally produced in high-volume internal mixers. This technology has remained essentially unchanged for the last ninety years, its advantage being the high flexibility in terms of varying recipes and mixing instructions. A disadvantage of the discontinuous, batch-by-batch production of rubber compounds in internal mixers is that this process can lead to differences in compound quality from one batch to another. Another disadvantage is that the cross-linking chemicals have to be incorporated in separate stages due to the limited cooling capacity and the high compound temperatures that cannot be reduced as a result. This leads to high energy, storage and personnel costs.

Quality differences can be prevented with the aid of a continuous mixing procedure owing to the consistent proportioning of compound components and uninterrupted operation of the mixing unit with static process conditions. This process also features a significant reduction in energy consumption with equal or enhanced compound and vulcanizate properties.

The work described in this paper contributes above all to clarifying the principles for the continuous production of rubber compounds containing fillers, including cross-linking chemicals in the twin screw extruder, as well as the correlations between processing parameters, e.g. screw revolutions, and compound and vulcanizate properties, such as filler dispersion and tensile strength. It is typical to use pourable Rubber/Filler-Composites (RFC's) based on NR/carbon black, E-SBR/carbon black and E-SBR/silica/silane.

In the studies, rubber compounds are produced in both the internal mixer and the twin screw extruder. The properties of the compounds from the internal mixer and the resulting vulcanizates serve as reference values. A co-rotating twin screw extruder is used for continuous compound production.

Based on the test results, it can be established that vulcanizable rubber compounds can be produced in a continuous procedure on the twin screw extruder by using RubberFiller-Composites (RFC's).

The level of compound quality attainable when evacuated from the co-rotating twin screw extruder is determined by the compound quality achieved in the plasticizing zone.
Compound temperatures and material properties that can be compared with the values from the base mix level in the internal mixer are determined using material-specific mixing element combinations after the plasticizing zone. This consonance appears when processing NR/carbon black RFC’s by interconnecting forward and reverse conveying kneading blocks in the plasticizing zone. For the E-SBR/silica/silane RFC, this optimum is found using forwarding and neutral kneading blocks. The high cooling efficiency of the twin screw extruder makes it possible to bring the compound temperature up to the feeding point for the cross-linking chemicals down to below 120°C. It is possible to produce the base and the finished compound in the twin screw extruder constant over time and at different locations.

Attainable compound properties are affected by the residence time of the rubber compound in the twin screw extruder. Under this project a measurement technique was developed for determining the residence time based on the addition of an indicator. The indicator is activated by UV hand lamp to a blue fluorescence in the wavelength range of 366 nm. The measurement technique enables optical recognition of the indicator along the processing zone during extrusion. Mean compound residence times in the twin screw extruder FTX-80 of, for example, 25 seconds were measured with a throughput of 50 kg/h.

Compound properties can be improved by using high screw speeds. However, the proportional increase of compound temperature in the extruder with the increase in screw revolutions can lead to thermal damage to the rubber or partial curing of the rubber compound. It can be derived from this that continuous production of rubber compounds in twin screw extruders must take place under maximum possible utilization of the engine output with minimum possible screw revolutions.

Taking the results of the basic studies, an optimal screw configuration was developed for the rubber compound based on an NR/carbon black RFC. Compared to the internal mixer compound, the same filler dispersions and tensile strengths were identified with a specific energy input that is smaller by a factor of three.

An optimal screw configuration could not be developed for the continuous production of rubber compounds based on the E-SBR/silica/silane RFC within the basic studies. In comparison to the reference values from the internal mixer, the Mooney viscosities and the amplitude-dependent storage module of the continuously produced compound are
considerably higher. If, after a storage time of 45 minutes, the rubber compounds are
subsequently subjected to a shear load from three forward conveying kneading blocks in the
extruder, a significant improvement in the Mooney viscosity and the amplitude-dependent
storage module can be identified.

To reduce retooling times, a procedure was established with which all three rubber
compounds can be produced. This procedure eliminates retooling work by using screw
configurations and cylinder setups that need not be converted when the compound is changed.
Using the no-conversion procedure with a throughput of 25 kg/h, compound properties
attained, e.g. Mooney viscosity and filler dispersion, as well as the vulcanizate’s properties
such as tensile strength, elongation at tear and hardness, are comparable with the properties of
the reference compounds from the internal mixer.

The specific energies applied in the continuous mixing process within the range of 0.24
kWh/kg to 0.3 kWh/kg are lower than the energy inputs in the internal mixer by the factor 3
(NR/carbon black RFC) to factor 6 (E-SBR/silica/silane RFC).

With increasing mass throughput, a proportional increase of output temperature and a
reduction of specific energy input can be ascertained on the twin screw extruder FTX-80. The
rising output temperature limits the maximum attainable mass throughput under 120°C in the
case of rubber compounds based on an NR/carbon black RFC or an E-SBR/carbon black RFC
to 50 kg/h, and in the case of E-SBR/silica/silane RFC to 37.5 kg/h. With increasing mass
throughput, a degradation of the compound and vulcanizate properties was determined that is
most pronounced in compounds based on the E-SBR/silica/silane RFC.

As a whole, the continuous production of rubber compounds based on rubber/filler
composites is primarily determined by screw configuration and the mixing temperatures
occurring in the twin screw extruder. The mass temperature during mixing influences the
properties of the rubber compound and also represents the output limiting factor. The main
requirement on a twin screw extruder for the continuous production of rubber compounds is
therefore to have maximum cooling efficiency for the extruder cylinder.
Studies performed by way of example on rubber compounds based on an NR/carbon black RFC investigating to what extent approaches developed in the laboratory can be applied to extruders in a manufacturing environment show that the compound’s properties are virtually independent of the size involved. Rubber compounds based on an NR/carbon black RFC can thus be produced on an industrial scale. Based on the maximum mass throughput of 200 kg/h achieved on the production extruder, the exponent of the model theory originating during plastics processing is corrected when projecting the mass throughput from a laboratory to a production extruder for the continuous production of rubber compounds.