The Next Generation in Rubber Injection Molding

Manfred Arning
LWB-Steinl, Altdorf/Germany

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In the recent years developments have been made by machine and mold manufacturers, as well as engineering companies, to increase the production efficiency of rubber injection machines by means of implementing systems to reduce the cure time. When the first rapid cure technology was presented about 4 years ago, most processors were very skeptical about the technology. Today almost every machine manufacturer in the industry offers a solution for reduced cure times. All these systems are based on dissipation during the injection process to increase the temperature of the material entering the cavity. One can say, that all these systems have shown, that cure time reductions are possible. However, also the differences of these systems have to be considered thus following these are compared.

General considerations

The biggest fear of every processor is the danger of premature cure of the material in the injection unit of the machine or in the runner or cold runner system. The system should also provide biggest possible flexibility for the existing processes used and available molds. Cost in an other issue to be considered.

The material temperature when entering the cavity is playing an important role for the cure time. In *Fig.01* a cure diagram for a natural rubber product with a wall thickness of approx. 1.6”. The 3 different colours in the diagram represent the state of cure. Especially for thick wall thickness products, the material temperature is the key factor for a reduced cure time [1]. For this product a tremendous cure time reduction is possible with a higher material temperature irrespective of the mold temperatures used.

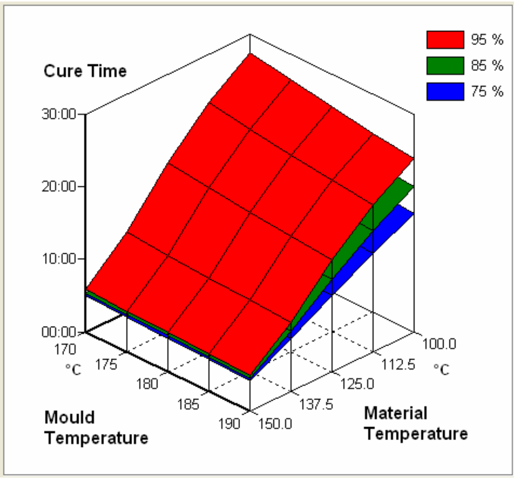

Fig.01 Cure diagram
[Source: Krehwinkel&Schneider]

One aspect to be looked at is the change of the material viscosity in dependence to the temperature. With an increase material temperature the viscosity is reduced, thus a better material flow and reduced injection pressure and clamp force requirement are achieved. *Fig. 02* shows the temperature dependence of the viscosity [2].

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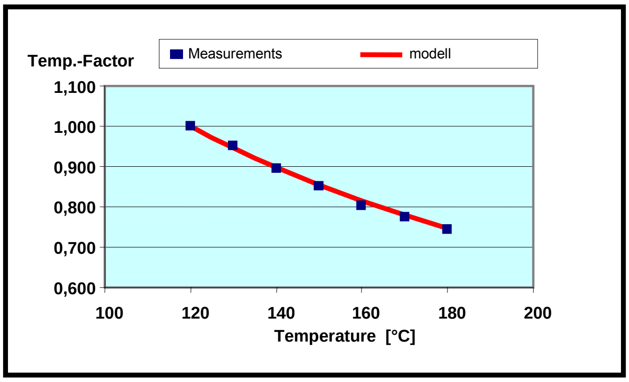


Fig.02 Temperature dependence of the viscosity

Considering that the material in the cavity needs the higher temperature for reduced cure times, varies possibilities exist.

1. Mold related sytems

In conventional mold designs a increase of the material temperature entering the cavity is achieved by the runner and gate design *(Fig. 03, detail 1)*. However, this method has its limit due to the product design and the high energy created by very small gates.

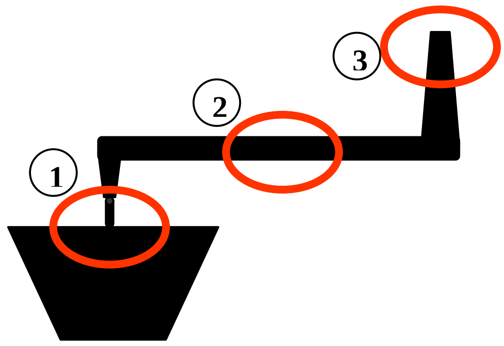
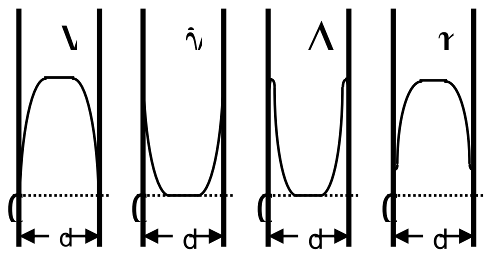


Fig.03 Methods to increase the material temperature during injection

At the last International Molding Conference a mold feature was presented to increase the material temperature in the mold by means of a system known from the plastics industry (*Fig. 03, detail 2*) [3].

Mold related systems exclude the possibility for premature cure of the material in the injection unit, however, certainly have their limits due to the fact, that the temperature is increase relatively late in the process. Therefore the material is leaving the nozzle at a relatively high viscosity thus injection pressure and clamp force required remain unchanged. Existing molds would have to be modified and the system does not allow an adjustment to material changes.



v Flow speed

γ Shear speed

ΔT Temperature difference

η Viscosity

Fig.04 Rubber behaviour in a channel

2. Machine related systems

One possibility for a material temperature increase is the use of small injection nozzles (Fig. 03, detail 3). Similar comments as made for the mold related systems also apply for this concept, i.e. the nozzles are not adjustable and extreme temperatures may arise due to the high friction in small nozzles *(Fig. 04).*

Another possibility is the use of a hydraulically controlled needle operated inside the machine nozzle [4]. Such a system offers the advantage of adjustability. However, the needle is always installed in the nozzle (unless exchanged against a standard nozzle) thus the material may always exposed to additional friction. The needle shut-off nozzle must be designed in such a way, that all material which has been exposed to friction is injected completely, thus scorch in the material of the following cycle is eliminated.

The original concept for reduced cure times is the EFE-injection system, based on a FIFO-injection unit plus a subsequent injection plunger to inject all material out *(Fig.05/06)* [5]. The All-Out technology guarantees a material-free injection nozzle after injection. Therefore scorch in the following cycle is completely eliminated as no material stays in the nozzle. The processor has the choice of a fine adjustment via the machine

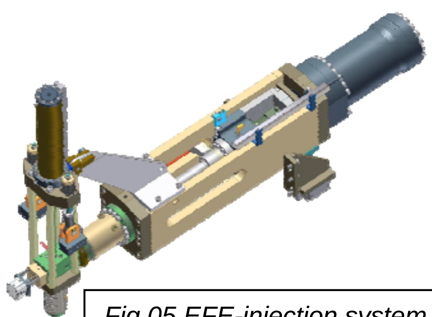


Fig.05 EFE-injection system with Rapid Cure Function

controller *(Fig 07),* i.e. the system allows a very precise and repeatable setting of the additional energy required. Also the option to add no additional energy to the material during the injection is given.

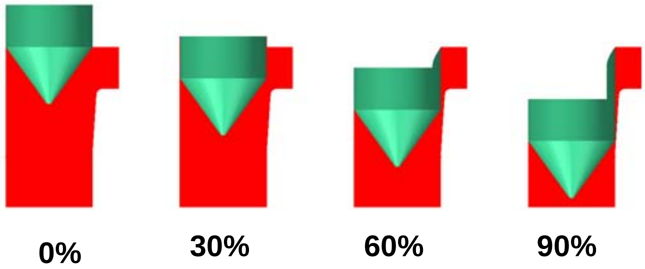


Fig.07 Position of the secondary plunger for the Rapid Cure Function in the EFE-injection system

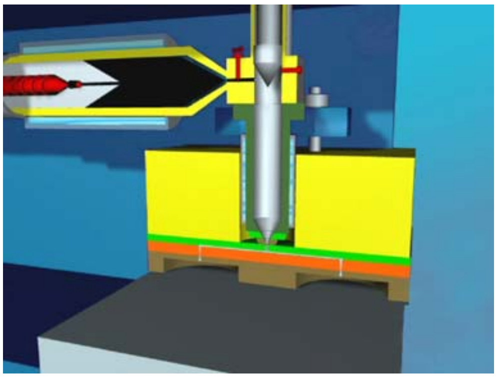


Fig.06 Principle of the EFE-injection system

The pressure and temperature measurements in *Fig 08* show a typical cure, i.e. with the plunger retracted (in 0%-position) respectively up to a closing of about 30% only a slightly higher pressure loss = increased material temperature is achieved. Depending on the position of the secondary nozzle (throttle position) the pressure requirements are increased to process the material and the temperature develops accordingly. The correlation between pressure and temperature development is obvious and confirms the theoretical temperature development based on the equation for the abadiatic temperature increase by means of dissipation

$$\Delta \overline{T} = \frac{\Delta p}{\rho \cdot c_p}$$
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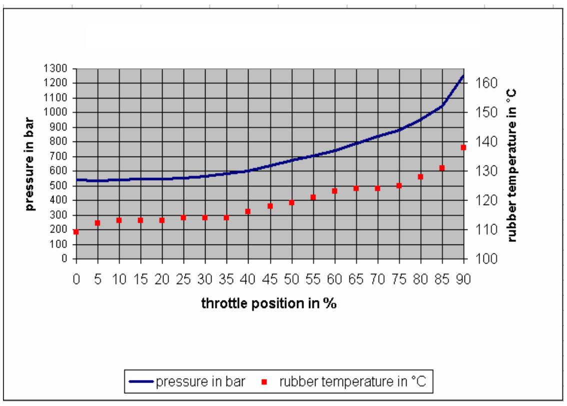

Fig.08 Pressure and temperature depending on the throttle position

Fig.09 Rubber products molded with the EFE-technique, with cure time saving between 40 – 50%

Fig.10 Rubber-to-metal bonded products molded with the EFE-technique, with cure time saving between 23 – 50%

3. System by means of online expert system
A different approach is the use of an expert system interfaced to the respective machine controller or integrated in the controller *(Fig. 11)* [6]. The system can be installed to basically every machine. With detailed information about the process the system optimizes the parameter settings of the machine. The system basically tunes the machine settings for an optimum cure time. Expert systems can also be added to machines using above indicated other techniques to ensure constant state of cure thus repeated and consistent product quality.

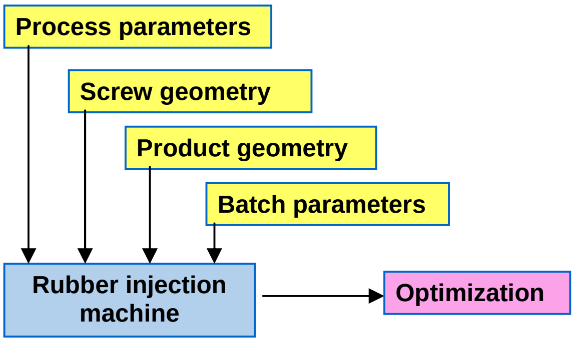

Fig.11 Expert system for cure time optimizing

One economical aspect of the Rapid Cure Technology, besides the possibility to operate with cure time reductions up to 50% (depending on what system is used), is an increased number of cavities for molds operated with the injection-transfer-molding method (ITM). By means of a higher material temperature and consequently reduced viscosity, a larger ITM-pad can be used.

For a plug as per *Fig. 12* the original ITM-pot diameter of approx. 16” a clamping force of 165 US-tons is required without the Rapid Cure Function, i.e. a transfer force of approx. 0.82 US-tons/inch². With the Rapid Cure Function the transfer force could be reduced to 130 US-tons or 0.65 US-tons/inch², besides a reduced cure time of approx. 25%. Using the same machine size with 165 US-tons the ITM-pad can be increased to approx. 18” achieving a considerably higher output.

Fig.12 Plug, EPDM 50° Shore

The systems described above are basically all working on the principle of increasing the material by dissipation, except the expert system, which is cutting out safety margins from the process and optimizes the process parameters. Another system exists, which is working on the basis of material temperature increase by means of heat transfer. For this Ultra-Short-Vulcanizing process (USV) a special injection unit has been developed and patented, allowing a very gentle temperature increase of the material before injection. Although this system is still covered under an exclusively agreement, the following shows the tremendous possibilities, if developments are done with regard to the rubber injection units.

4. All-Out Technology
Basis for this injection unit technology, like for the EFE-Technique, is the All-Out philosophy as also used in the EFE-system. The All-Out technique *(Fig. 13)* is based on a separate plasticizing cylinder with a separate injection chamber/plunger. The material is plasticized through the injection nozzle into the injection chamber. Once the injection volume is reached, controlled by an electronic stroke measuring system, the injection chamber is lifted up; the plasticizing cylinder retracts, followed by a

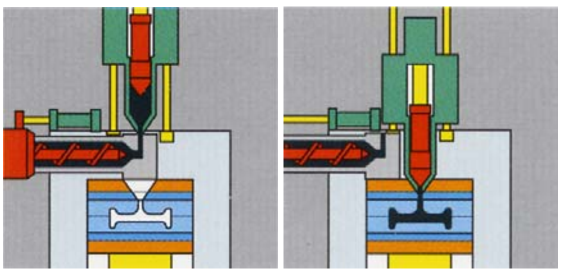

Fig.13 System sketch All-Out-Technology

down stroke of the injection chamber towards the mold. Because the plasticizing cylinder is moved out, the system can work without a non-return valve and offers an extremely high precision. The material is injected by means of a hydraulically operated injection plunger. All material is injected out of the injection chamber and nozzle. No material remains in the system. Without the All-Out technology the EFE-injection system as described above would hardly work. Also the USV-technique is based on this feature.

5. Ultra-Short-Vulcanising (USV)
The basic idea and target for the development of the USV-technique was a cure time reduction allowing the use of single-cavity molds rather than 4-cavity molds for certain rubber-metal-bonded products with the same output. Therefore the cure time would require a reduction of about 70% compared to a conventional machine, actually a reduction from 390 sec. to 120 sec..

The basic thoughts are the same like discussed above: the material has to enter the cavity with a higher temperature compared to a conventional technique. However, rather than using dissipation increase the material temperature, the USV-technology is based on the principle of heat transfer, i.e. the material is heated up prior to injection in the injection cylinder to the desired temperature. Again, if the material is heated up in the injection cylinder the system must inject all material out completely to avoid premature cure of any remaining rubber for the next injection cycle. Therefore also this technology is based on the All-Out philosophy.

As a result of the development an injection unit had been designed, which consist of a horizontally arranged FIFO-injection unit plus a secondary injection plunger. Contrary to the EFE-technique, the material is injected through the injection nozzle into the secondary injection cylinder *(Fig. 14)* [6]. After the initial injection into the secondary cylinder, the material is heated up before it is injected. However, due to the bad heat conductivity of rubber, a standard cylinder can not be applied. A ring cylinder was designed *(Fig. 15),* working in conjunction with a ring plunger. Of course, also the injection nozzle needs to be of a special design. Existing mold may not be used for this technology.

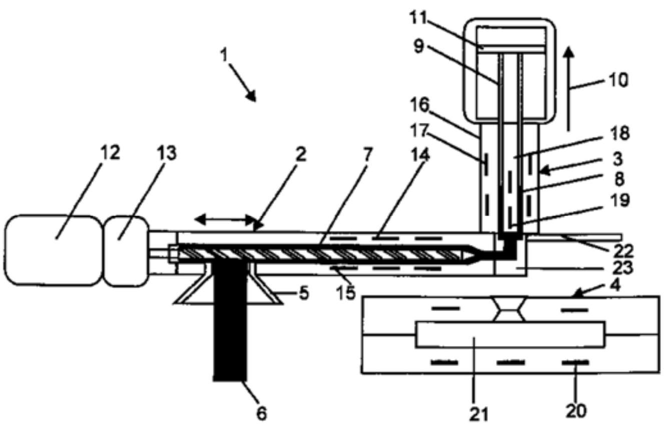

Fig.14 Principle sketch of the USV-injection unit

The material is plasticized and injected into the secondary ring cylinder. The wall of the cylinder is heated to the desired temperature by means of oil temperature control units. Before injection into the mold, the material is heated up.

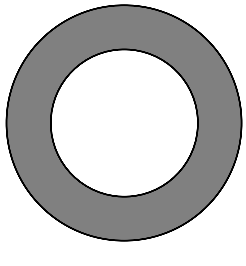

Fig.15 Ring cylinder and ring plunger of the USV-injection unit

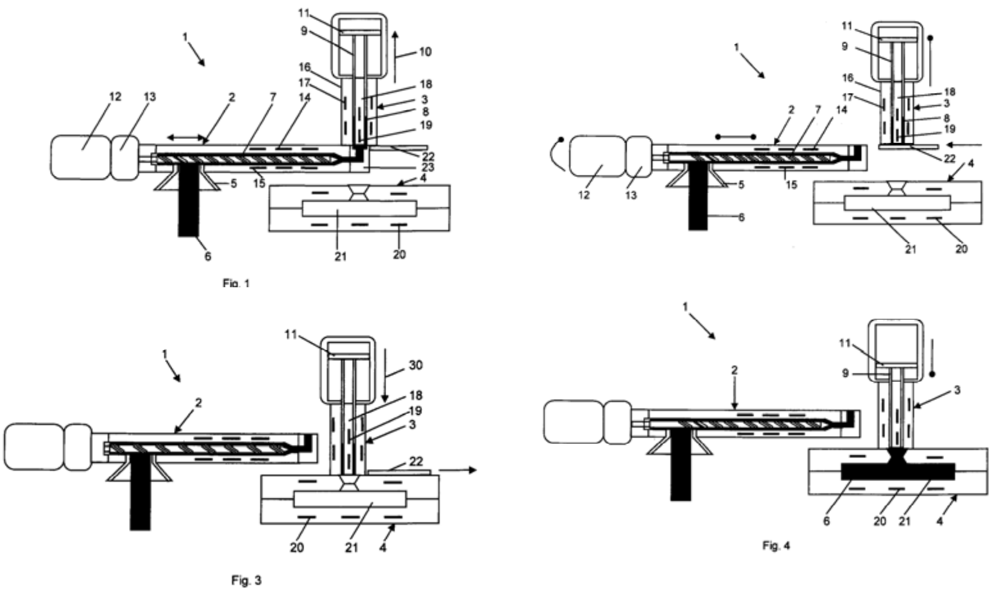

Fig.14.1 1) Inject the material into the secondary injection cylinder
2) Lift secondary injection head and retract plasticizing cylinder
3) Secondary injection head onto mold
4) Inject

The dwell time of the material in the secondary injection cylinder depends on the compound used, the temperature to be achieved and the thickness of the plunger ring. In *Fig 16* a typical heat up behaviour of the material is shown.

The USV-technology is in used and the results are very promising. This technology may not be the answer to each and every production task; however, certainly it is opening up a new possibility for much faster and more economical rubber product manufacturing.

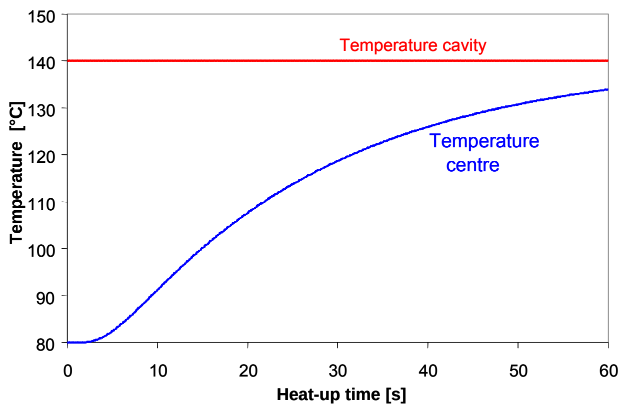

Fig.16 Dwell time of the material in the secondary injection cylinder (=heat up time prior to injection)

The USV-technology provides a rather high flexibility for certain product groups, depending on the production volumes. The use of single cavity molds largely reduces the expensive times to change molds and start up an operation. How much efforts (and cost) can be saved in the approval and certification process, considering that the prototype mold is identical to the production mold? Mold cost is largely reduced and cavity modifications are required in less cavities.

The USV-process is clean and free of any old materials, as all material is always injected completely. Problems of the rubber distribution in a runner deck, whether in a cold runner system or hot runner system, are completely eliminated. Never again an unbalanced filling of cavities.

All USV-machine manufactured are based on the vertical VC-class machine range *(Fig. 17).* However, the injection unit can also be employed at other models and horizontal injection machines.

Fig.17 USV-machine with 55 tons clamping force

6. High-speed clamp system

Reduced cure times open up strategies for different production methods concentrating on the overall cost of injection molding. All of a sudden, the cure time is close to times known from the plastic industry. This ends the times of “gemütliche” rubber injection machines with seconds required for opening/closing, especially when automation is integrated into production cells. Automation guarantees a repeatable handling time and is done by brushes, linear handling systems or multi-axis articulating robots. What would be more appropriate looking to the thermoplastic molding industry? Plastic and rubber processing can not simply be compared; however, the clamping unit would be an area where the rubber industry can watch out. The clamp is providing a certain clamping force and opens and closes the mold. These functions are pretty much the same for plastic and rubber processing.

The 2-platen clamping system *(Fig. 18)* does not only offer high speed. In addition it is providing a considerably smaller foot print compared to other systems with the same daylight and opening stroke *(Fig. 19*), whereas the machine length is irrespective of the injection volume.

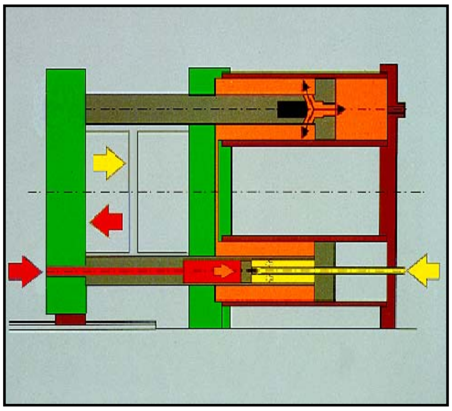

Fig.18 Fully-hydraulic 2-platen clamping system

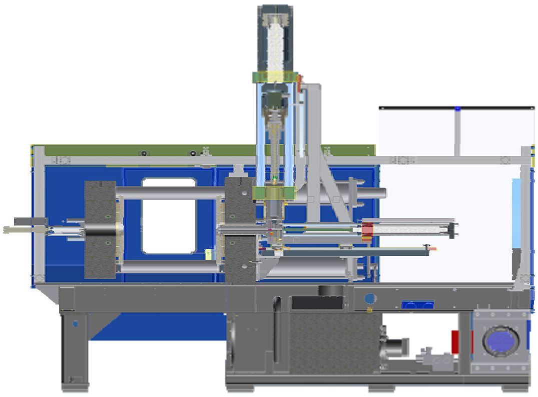

Fig.19 2-platen injection machine with EFE-injection system

Simply copying a clamp system from a plastic injection machine may invite difficulties when processing rubber. Therefore the stationary and movable machine bolsters are modified paying attention to the special requirements for rubber injection. Also the standard speeds of plastic injection machines may not be required for the manufacturing of rubber parts, considering that the molds can not be opened that fast due to the adhesion of the rubber parts to the cavities. Therefore the hydraulic drive is downsized, still allowing opening of the maximum stroke in about 1.4 sec. and closing in about 0.7 sec.

As the clamp systems are originally designed for high speed applications in combination with a few seconds cooling time, thus short production cycles, when processing rubber the clamp systems are operated far below their limits.

The interesting combination is a high speed 2-platen clamp concept in combination with a Rapid Cure injection unit, as shown in the cycle time comparison *chart 1*, based on figures for a 300ton-machine (with estimated cure and handling times)

		Conventional machine	High-speed 2-platen clamp with Rapid Cure
Close clamp/mold	sec	**4”**	**2”**
Build up clamp force	sec	1”	1”
Vacuum	sec	2”	2”
Injection	sec	8”	8”
Cure	sec	**60”**	**45”**
Open clamp/mold	sec	**4”**	**2”**
Remove products	sec	15”	15”
Total cycle	**sec**	**94”**	**75”**
Number of cycles/hour		**38.3**	**48**
		100%	**125%**

Chart 1: Comparison of a standard machine vs a 2-platen high speed clamp with Rapid Cure

7. Summary

The discussion of reduced cure times started about 4 years ago and almost all machine manufacturers reacted with a respective technique. Each system may have its pros and cons, however, it is obvious that processors will have the possibility to reduce the cure times considerably.

The Ultra-Short-Vulcanisation is a technique developed and used in production for rubber-to-metal bonded products. This technology, also for all rubber parts, will allow manufacturing with even further reduced cure times for faster production cycles. This technology will allow a different view on the production of rubber products with smaller and less expensive machinery, reduced number of cavities with consequently lower cost molds and reduced manufacturing cost. This technology will also open up new possibilities for an economical production of rubber-to-plastic molded products in a 2-component injection machine.

The Rapid Cure Technology in combination with a fast and space-saving 2-platen clamp system will allow fastest possible cycle times. With automated unloading of products and, if applicable, loading of inserts, provide repeated fast production cycles with consequently consistent quality.

[1] Krehwinkel & Schneider, Cologn/Germany
[2] Dr. Volker Härtel, *Grundlagen für die Schnellvulkanisation*, Leipniz University of Hanover/Germany
[3] *David Rose*, Beaumont Technologies, Inc., *Flash Free Molding And Reduced Cycle Time By Using In-Mold Rheological Control Systems*, International Molding Conference 2007
[4] K-Zeitung March 2008
[5] Manfred Arning, *Strategies For The Reduction Of Production Cost Molding Rubber Products,* International Molding Conference 2007
[6] Axel Potthoff, Prozessoptimierungssysteme zur Optimierung des Gummispritzprozesses, 2006