How to reduce the cure time without damaging the rubber compound during injection molding?

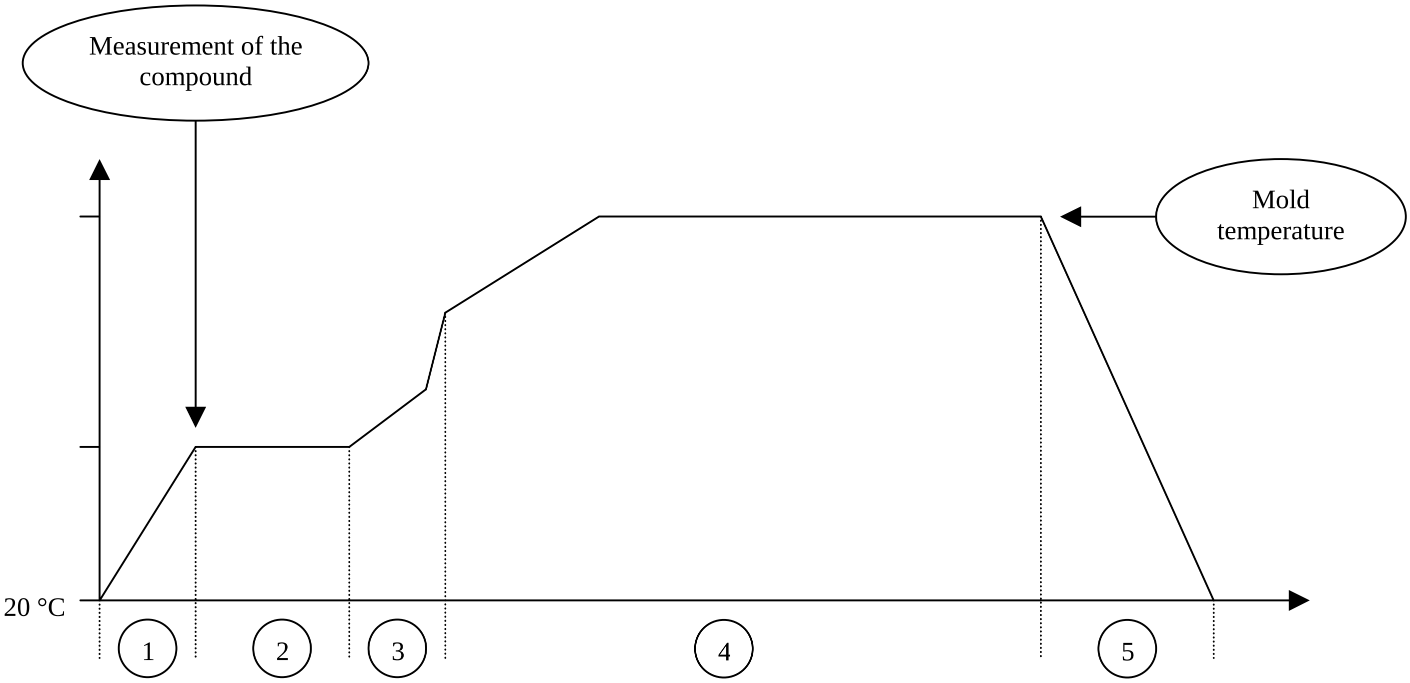
Introduction

This article aims at analyzing the rubber injection process and highlighting the limits that prevent cure time from being reduced. Afterwards some solutions will be proposed to overcome these limits and some industrial applications will be shown with values of improvement.

The injection process

In the rubber injection process, the compound has a thermal history that starts from room temperature when the rubber strip enters the extruder and reaches up to the finished part when it is cooled down to room temperature. In few cases, a post-cure process is done by putting the part in an oven for a certain period of time. This is a secondary process that won't be covered or spoken about in this article.

The compound thermal history can be summarized in the simplified graph below. This graph is simplified because it assumes that all parts of the compound have the same history, which is not true as further explained below:



Rubber compound thermal history in injection process

Area 1: compound preparing (the extrusion). The compound is plasticized and heated to reach the optimum temperature. This temperature has to be measured so that it can be optimized and maintained in the next step of the process.

Area 2: the storage. The compound is inside the injection chamber, ready for injection. Its temperature should be constant.

Area 3: mold filling (the injection). Flowing into the runners causes the compound to heat up. Heating-up is mainly generated through compound shearing but also by contact with the hot mold walls.

Area 4: the curing process. Once the cavity being filled, the compound has not yet reached the mold temperature even if it has undergone a self-heating process. It therefore continues to heat during the beginning of the curing phase (area 4) until reaching the mold temperature. Depending on the part thickness, the heat-up process will be more or less fast.

Area 5: the cooling process. Once the part being extracted from the mold, it needs a certain amount of time to cool down and continues to cure. A total control over the process also includes a control over the parts cooling conditions.

What has been done in the past to reduce cure time?

The following orientations have been followed over the years and brought improvements:

Separating the screw and piston

This was the first step that allowed the process conditions to be optimized due to a better adjustment of the extruding conditions and a check of the process result through a real compound temperature measurement.

Temperature regulation

Having an accurate temperature control loop is necessary to have a consistent injection unit temperature and mold temperature. As for the mold, there is a distance between the heating platen and the cavity so there can be a big and variable difference in temperature between both. To control the process, it is very important to regulate the cavity, which is where the compound is. This makes the regulation loop more difficult to do, but makes the process much more consistent, can allow for higher mold temperature and cure time reduction. This is what ThermoTrac is doing.

Mold temperature balance

The outside surfaces of the mold create heat loss that cools down the sides of the mold. This is called the edging effect and will induce a lower mold temperature on the sides and corners than in the center of the mold. The mold temperature is limited by the highest temperature cavities, and cure time is given by the lowest temperature cavities that create a longer-than-needed cure time. Isothermould has been developed to compensate the edging effect and put all cavities at the same temperature, thus reducing cure time.

Safety margin removal

For a safer process and to compensate for all compound and process variations, all rubber processors add a safety margin to the cure time. CureTrac has been developed to compensate in a closed loop model for all those variations. This allowed removing the safety margin and having a constant cure state instead of a constant cure time. This allowed reducing the average cure time.

Increased injection pressure

As previously reported, there is a warming up of the compound during injection molding generated by shear, which is the friction between different compound layers inside the flow. This general principle is based on the fact that the higher the pressure is, the higher the compound temperature is when entering into the cavity. Compound having a higher temperature will cure faster. We have built injection units up to 3,000 bar to be able to reduce cure time. This has been the most common approach in the last few years and is still promoted on the market.

But this principle has a dangerous limit, which is what level of shear the compound can support. Shearing and stressing the compound too much will affect it and have consequences on the final rubber part's characteristics. This can be immediately measured on characteristics, but this might shorten the lifetime of the parts too. On top of that, if there are runners, there is a risk of scorching before the compound reaches the cavity.

> Increasing compound temperature by excessive shear can damage the compound, affect the part's characteristics and reduce lifetime of the rubber product.

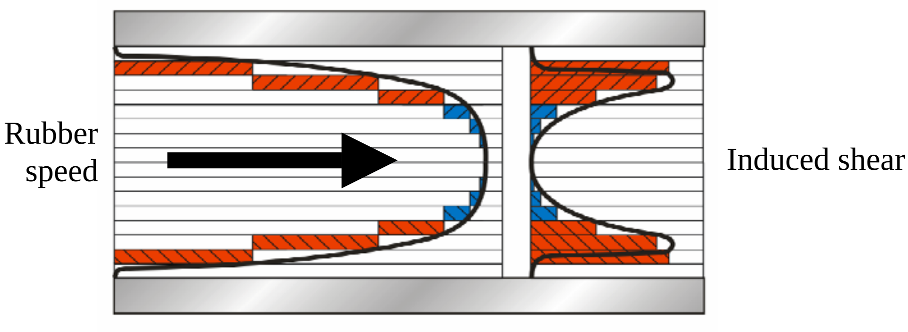
What are the limits that prevent cure time from being reduced?

Analyzing the flow during injection molding shows that shearing and warming up are very different depending on the locations in the flow.

This heterogeneous warm up causes heat to concentrate in some regions, which will be the first to be affected by excessive shear, compound degradation and scorching. These regions will limit the global possible warming up. On the other hand, some parts of the compound will have very little shear and thus very little warm up during injection molding. As these parts of the compound are the coolest one, the final cure time will result from them.

The laminar flow effect

To understand this effect, let's look at what a laminar flow is.



Compound speed and shear in a flow

The compound is sticking (no speed) against the runner wall whereas the center of the flow is the fastest. The shear is the difference in speed between layers that causes friction between them. On one side, the adjacent laminates have very big difference in speed creating high shear and warm up in the outside layers of the flow. On the contrary, in the center of the flow, adjacent layers are all flowing at nearly the same speed, creating low shear and low warm up. The result is a high temperature on the outside versus a low temperature in the center of the flow.

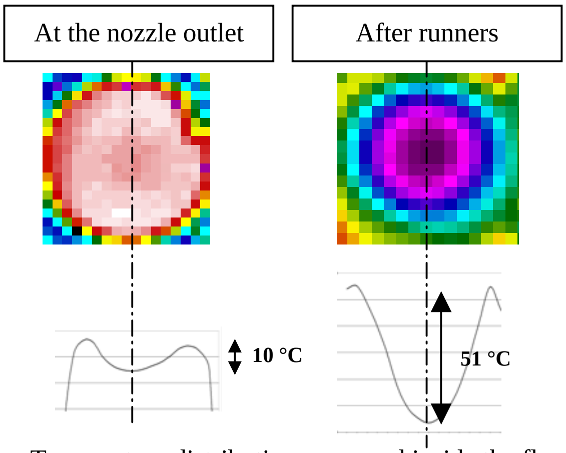
This laminar flow effect is true in every rubber flow, in the injection unit, in a Cold Runner Bloc or in the mold.

When examining more closely what happens inside the mold, the runners walls are also at high temperature which will add some warm up by contact (conduction) to the outside layers of the flow and not to the inside.

The global result will be a much higher temperature on the outside laminates than in the center of the flow.

Temperature in a rubber flow

We have measured this difference with a thermal camera, using an average case (NBR 75 Sh). We found a difference of 10°C when the compound is coming out of a 5mm-diameter nozzle and of 51 °C after adding 250-mm-long runners of 8-mm diameter.

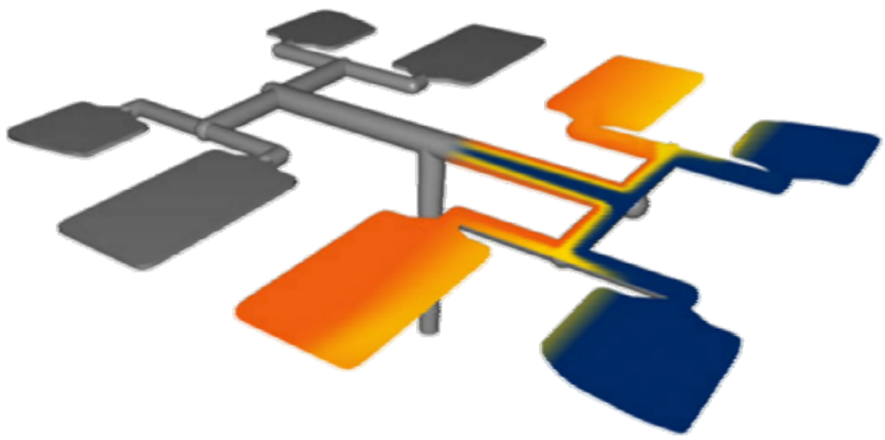


Temperature distribution measured inside the flow

The laminar flow will not let the opportunity for the outside and inside layers to mix, so this temperature difference will increase over the flow length and lead to high temperature heterogeneity in the cavity at the end of injection.

Only one portion of the compound will dictate the cure time: the low temperature part.

The runners split effect



Temperature of the compound inside the flow in a multi-cavities mold

As the highest temperature compound is on the outside of the flow, when a runner is split, this high temperature compound entirely flows on the inner side of the secondary runner and the compound from the center goes to the outer side of the secondary runner. At the next split, the high temperature compound entirely goes to the inner cavities and the coolest compound goes to the outer cavities.

There is a difference in compound temperature between cavities. Every rubber processor dealing with multi-cavities molds has seen unbalances in filling even with a perfect mold temperature balance and identical runners and gate size. The reason is that this temperature difference changes the compound viscosity from one cavity to another.

A common way to address this unbalance is to adjust gate sizes and restrict the gate with the higher flow. The higher flow is at the highest temperature, so reducing gate size for this cavity will address the filling but will increase the thermal unbalance.

TurboCure®

As the mold can only be opened all at one time, only the low compound temperature cavity will determine the cure time, whereas the high compound temperature cavity will determine the injection pressure and mold temperature limit.

> Only few cavities will dictate the cure time: the low compound temperature cavities.

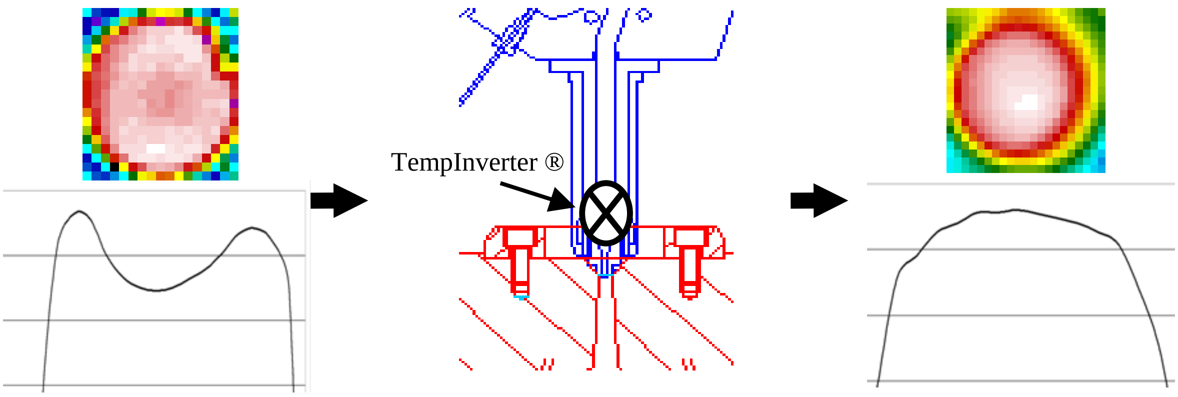
Solutions

As previously stated, the cure time is determined from the rubber in the center of the flow whereas the limit is determined from the rubber on the outside of the flow.

The global solution is called TurboCure® and is made of 3 different modules: TempInverter® in the injection unit, FillBalancer® at the runner split and FillBalancer® Max before entering the cavity.

TempInverter® (Patent pending)

The first part of the solution is to let the outside temperature increase and after, to invert the center and the outside of the flow. This is what TempInverter® is doing by driving the outer compound to the center of the flow and driving the inner compound from the center to the outside. This system is placed just before the nozzle so that the outer temperature has already increased (in the nozzle drop) and will be placed in the center of the flow. This will increase the temperature in the center by about 10 °C.

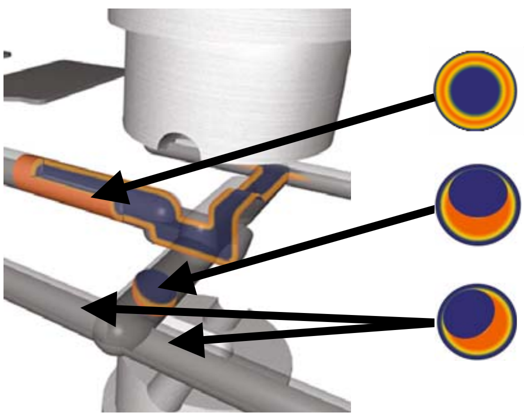


Temperature measurements inside the flow coming out of the nozzle without and with TempInverter®

Increasing the temperature in the center of the flow will reduce the cure time.

FillBalancer® (Patents 6.077.470 & 6.503.438)

The unbalance at runners split is due to non-symmetric temperature in the flow after the split. By performing a rotation of the flow, the symmetry can be obtained in the secondary runner. This rotation is operated by the FillBalancer®.



The shape at the runner division allows for the flow to arrive from bottom instead of from the side. The high temperature compound will then be at the bottom instead of on the side, therefore symmetrical to the next division. Compound flowing into each runner branch will be in the same status, thus ensuring a balanced temperature and flow between cavities.

The cure time is reduced due to increased number of low compound temperature cavities.

FillBalancer® is using a world patent from Beaumont Technology Inc. that has been used in thermoplastics for many years using the brand name of MeltFlipper®. The shape is highly dependent on the mold configuration, and varies depending on the sprue division effect, number of cavities, and runners' shape. Beaumont has a large experience in the design of those shapes and REP has the know-how for rubber specificities: together they offer a solution that combines the design of the most appropriate shape for a given application and the supply of the license needed for this technology.

Filling balance advantages

The advantage of thermal balance is cure time reduction but balancing the filling brings many advantages too. In case of unbalance, the pressure inside the first cavity to be filled keeps increasing because pressure is needed to fill the other cavities. This excess of pressure creates flashes on the parting lines and compound leaks at the inserts. The parts often require more time for deflashing and the mold requires more efforts and time to be cleaned at each cycle. On the other hand, there is less holding pressure in the last cavity to be filled which may therefore, show non-fills or bad bonding on inserts.
The non-fills create fouling and the accumulated dirt requires the mold to be more often removed from the press for cleaning. The setting of a press becomes then a compromise between the first and last cavity to fill, making the process window very narrow, so not very safe.

Improving the filling balance with FillBalancer® will improve all those issues on top of reducing cure time:
- Decrease flashes
- Reduce operator time on the press (less mold cleaning), so decrease total cycle time
- Reduce manpower to finish the part (easier deflashing)
- Save some compound (the flashes and leaks)
- Increase the number of cycles between cleaning (less flashes and less non- fills, so less dirt)
- Decrease scraps (larger process window, so safer process)
- Improve the part's characteristics homogeneity between cavities and improve global production consistency

On the whole, this will increase productivity and at the same time reduce costs for labor, energy, compound and maintenance. Return-on-investment is commonly achieved over a few weeks or a few months.

FillBalancer® return-on-investment is commonly achieved over a few weeks or months.

FillBalancer Max® (Patents 6.077.470 & 6.503.438)

The goal of this system is to ensure that the highest temperature compound is in the critical area of the part during injection molding. Since the center of the part is the last to cure, having the highest temperature compound in the center of the part will reduce global cure time.

Conventional FillBalancer Max®
Temperature distribution in the flow and effect on filling balance

The system will use the same principle as the previous one, but will combine it differently. By dividing the flow, rotating it and reassembling it, the high temperature compound that was on the outside is put in the center of the flow. Once again, increasing the temperature at the center of the flow decreases the cure time.

Pressure loss

With TempInverter®, fresh compound is put on the outside of the flow when entering the mold so that it can flow longer before being affected by scorching. The flow is improved and the global pressure loss is lower than in conventional systems.
In practice, TempInverter® permits to obtain a 10 % longer flow in the same conditions.

FillBalancer® also decreases the viscosity of the compound going to the last cavity to be filled, thus making the flow easier and reducing the need for pressure.

CRB

Using a CRB requires the location of TempInverter® to be changed. It can easily be put in the secondary nozzle of the CRB.
FillBalancer® can still be used in secondary runners when there are some. It can also be included in the CRB for better balancing.

Energy savings

This approach is optimizing the energy use by balancing the energy distribution and driving it to the critical area. In addition, reducing cure time will reduce the time the machine is used for the same production, and thus the time it needs power. On the whole, this is a significant reduction in energy requirements for a given production.

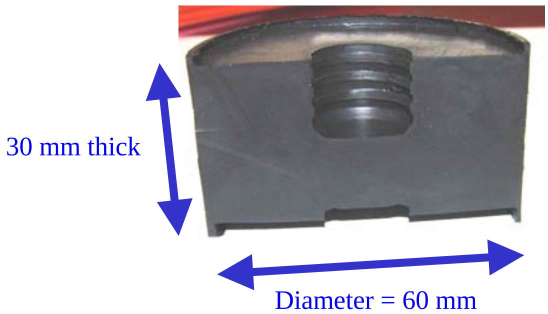
Soft for the compound

All modules of TurboCure® are applying the same principle; they manage the compound heating with a view to obtain a better homogeneity in the warm up. TurboCure is not increasing the maximum local compound temperature but is increasing the minimum local compound temperature.
The benefit on the cure time is achieved without stressing and damaging the compound.

TurboCure® is reducing cure time without stressing and damaging the compound.

Examples of industrial applications

AVS mount



TurboCure®

Compound: Natural rubber 50 Sh A
2 cavities used for those trials out of 8 in the mold
Mold temperature: 187 °C
Conventional cure time: 285 s
Cure criteria: static and dynamic part characteristics must be achieved + no undercure part visible when part is cut + no pre-cure mark

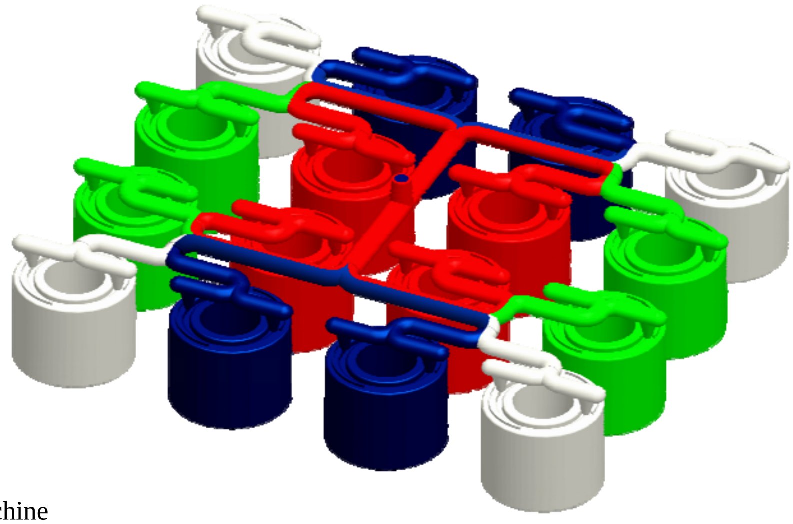
	Cure time	Improvement	Variation
Reference	285 s		
TempInverter®	205 s	80 s	- 28 %
Fill Balancer®	170 s	115 s	- 40 %
Full TurboCure®	140 s	145 s	- 51 %

This test shows the efficiency of TuroCure® achieving more than 50 % cure time reduction and it also shows that the modules can be added to each other improving the global efficiency.

51 % cure time reduction with TurboCure®

Bushing

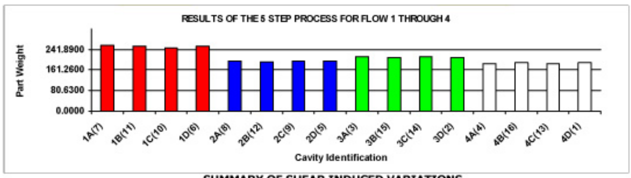
In this example, only FillBalancer® is used to obtain a better balance between cavities.



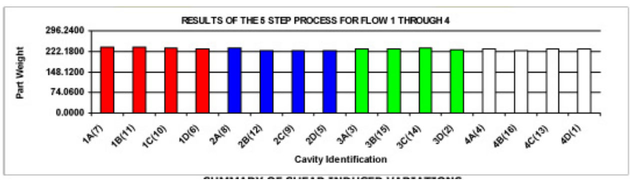
V68 / 400 T machine
200 g natural rubber per part
16 cavities

The mold balance was the following.

25.6 % unbalance
with conventional runners:



3.5 % balance
with FillBalancer®:



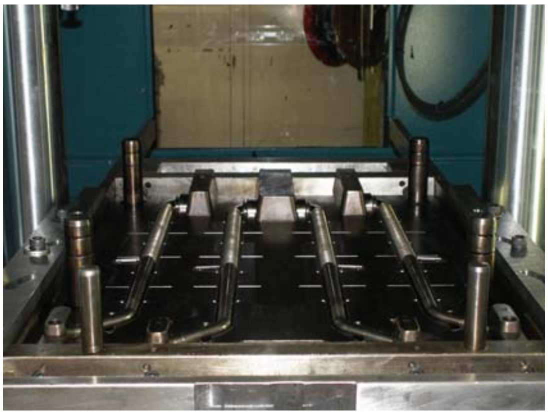
rep
rubber injection

The benefits were as follows:
- The cure time went down from 510 s to 300 s with FillBalancer®, achieving a 42 % reduction.
- Flashes and leaks at inserts have been reduced, saving 1,350-kg compound per year, reducing the demolding time and further increasing the productivity.
- Some deflashing operations have been removed, reducing the operator costs.
- Part’s static stiffness consistency from cavity to cavity has been improved by 27 % and global Cpk on the production has been improved by 29 %.

FillBalancer® reduced cure time by 42 % with also quality, waste and labour cost improvements.

Grommet

In this example, only TempInverter® is used.



The machine is a V59 (250 T), the compound is a 50 ShA EPDM and the mold has 4 cavities and a runner plate. Conventional cure time was 100 s and it has been reduced to 60 s by using TempInverter®. The improvment has been 40 s.

TempInverter® reduced cure time by 40 %.

Conclusion

TurboCure® is made of 3 modules that can be applied all together or individually depending on the application. It reduces cure time up to 50 %. It respects the compound integrity because it doesn’t shear and stress the compound too much. The quality is improved too.
These modules are based on patented solutions, which require a small license fee. They are very easy to include in a process.
This approach is revolutionary. It can be compared in terms of productivity and quality improvements to what was made when injection molding was invented at a time where only compression molding existed.