How to control dimensional stability in high performance tools

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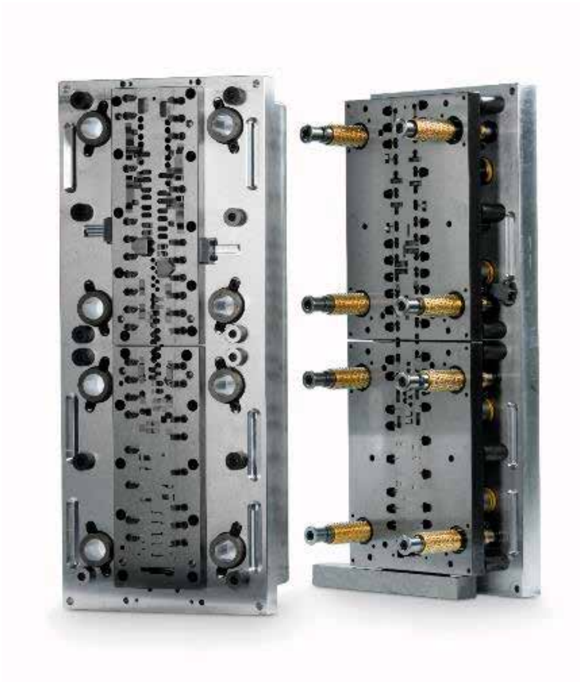
We are moving towards manufacturing of more high precision complex products that are made of more demanding materials were the room for error becomes smaller and smaller. Constructing a tool are often time consuming and expensive. That is why your tool need to be a reliable partner for a long time. One of the challenges that you might face is dimensional changes and dimensional stability. Mass production of a high quality and high precision product always starts with a high quality and high precision tool.

Note: This article will focus on the challenges that comes with dimensional changes, both from heat treatment and dimensional stability over time. Not to be confused with distortion, where the tool changes shape. This is caused by many other factors such as, design complexity, heat treatment conditions, and stresses from machining etc.



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The first issue you will face is the dimensional change that occurs during heat treatment. This change is instant and predictable in contradiction to the one that arise when retained austenite (RA) gradually transforms to martensite over time in use. During a correct heat treatment, the austenite transforms to martensite during quenching and tempering and the part will have a dimensional growth from this transformation.

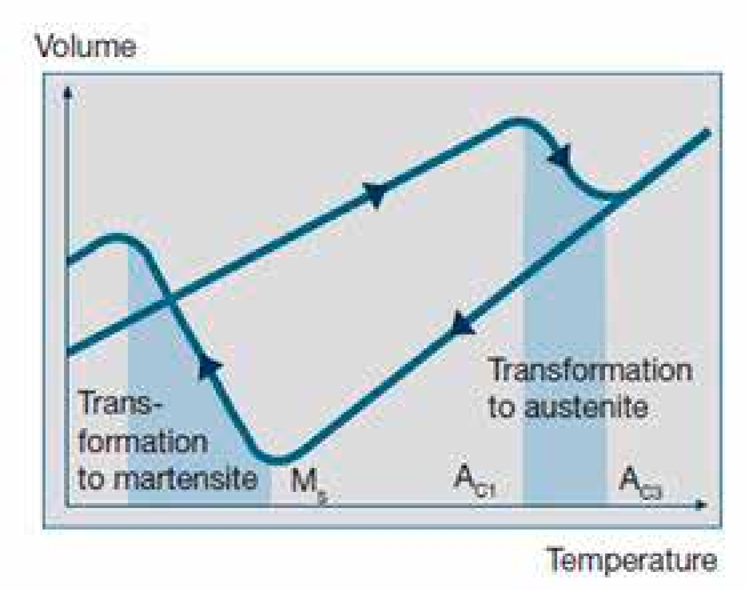

Fig. 1 Volume changes due to structural transformation

However, ingot cast steels with a high content of carbon and alloying elements show a large difference in dimensional change in thickness, width and length direction. The reason is that the microstructure is textured "stretched out" due to the segregation during solidification of the steel. Electro Slag Remelted (ESR) steels, such as Uddeholm Caldie, and Powder metallurgy (PM) steels, such as Uddeholm Vanadis 4 Extra SuperClean, are more isotropic and have much smaller differences in different directions than conventional ingot cast grades as AISI D2 / W.-Nr. 1.2379 due to a lower degree of alloy segregation. The ESR steels have typically also a lower carbon content compared with the conventional ingot cast ones.

Below one can see the difference in dimensional change for conventional ingot cast steel, ESR and PM steels.

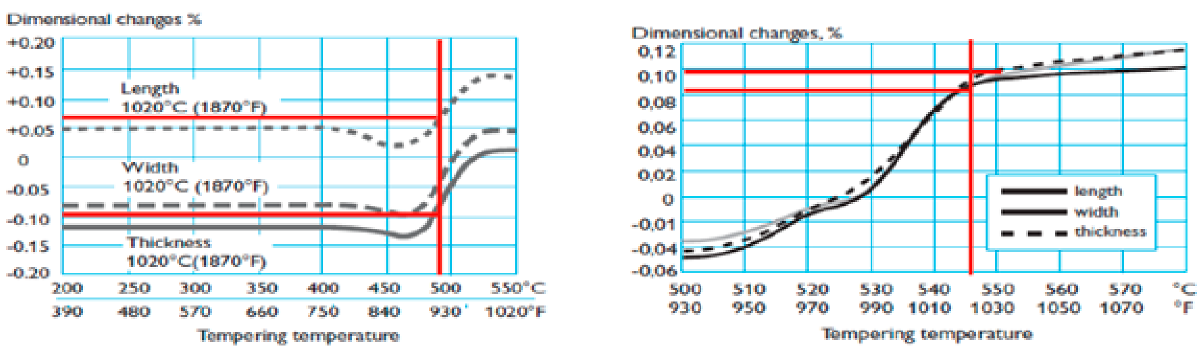

Fig. 2. Dimensional in changes conventional ingot cast steel (left), ESR and PM steels (right)

Is it possible to maintain dimensional stability over time?

To combine high hardness and good dimensional stability is often difficult when using a standard cold work tool steel grade like AISI D2/W.-Nr. 1.2379. To reach a hardness of 60 HRC you need to temper the steel at the secondary hardening peak which is located around 500-515°C. Tempering at this temperature means risk of high amount of retained austenite (RA). Since the RA is unstable, the dimensional stability will be low it will transform to martensite over time and thus cause the material to grow. To minimize the RA content you need to increase the tempering temperature to above 530°C with the side effect that the hardness might drop below your requirement. Another factor to consider that when using materials specified as international standards from various different suppliers the tempering temperature to avoid RA can differ quite a lot from batch to batch or between suppliers. Hence, there is no guarantee that your tool will have a good dimensional stability.

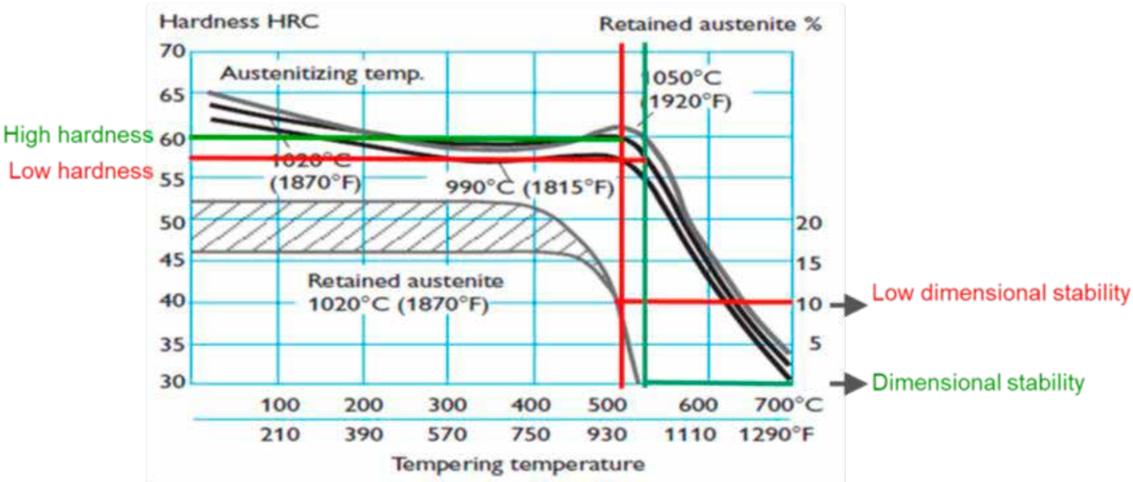

Fig. 3. Dimensional stability AISI D2

With many of the Uddeholm cold work steel grades developed for cold work it is possible to combine high hardness ≥60 HRC with good dimensional stability since the tempering can be done at a higher temperature, outside the area for having RA. Examples are the conventionally made Uddeholm Sleipner, the ESR steel Uddeholm Caldie or the PM steel like Uddeholm Vanadis 4 Extra SuperClean.

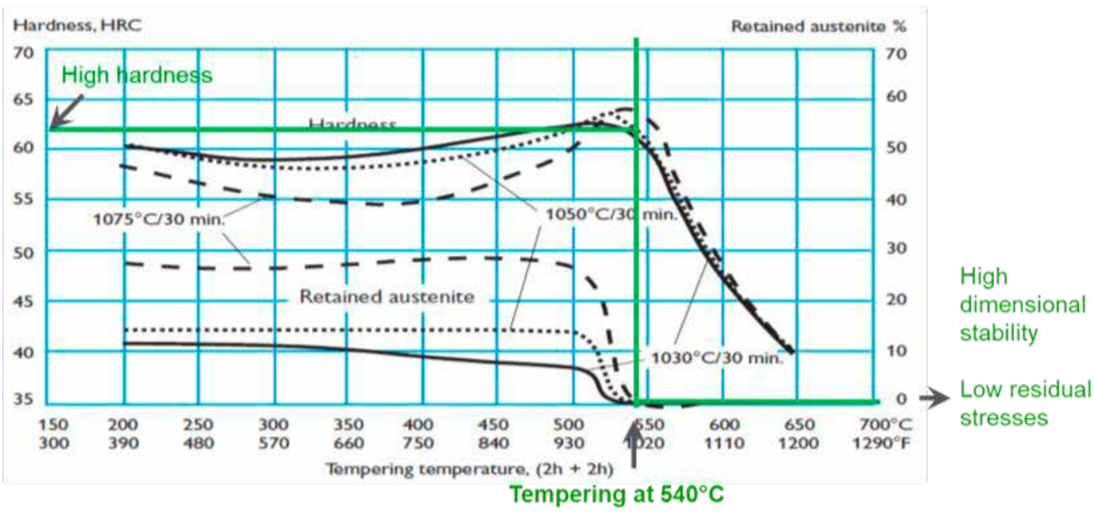

Fig. 4. Dimensional stability Uddeholm Sleipner

Is deep cooling needed?

In general, deep cooling is not needed, three or four high temperature tempering's give a very high dimensional stability in most of the tool steel. However, it can drive the martensite transformation a little further in the highest alloyed steel grades with a low Ms and Mf (martensite start and finish temperatures). Less amount of RA means better dimensional stability. Deep cooling is normally done at a temperature below -70°C. It should be carried out directly after quenching to secure a good transformation of the RA. Deep cooling will increase the hardness about 2 HRC if low temperature tempering is used. For high temperature tempered tools there will normally be no hardness increase but you might need to lower the tempering temperature about 20°C to have the same hardness as without deep cooling.

Example of multiple temperings of tool steel

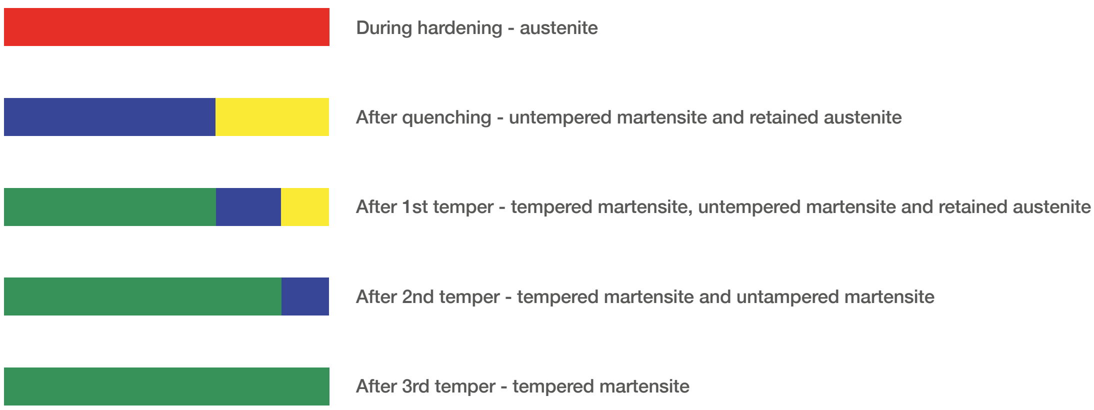

Fig. 5. Tempering of tool steel (schematic)

The long-term dimensional stability can be improved by adding one or several temperings as shown in the figure above. The extra tempering will reduce the retained austenite content to a minimum and by that prevent the possibility to material growth by phase transformation. As a rule of thumb, the last tempering temperature should always be the same or lower than previous tempering temperature in order to avoid untempered martensite at the end.

- Dimensional changes during heat treatment is unavoidable, choosing the correct tool steel will make it easier to manage.
- To keep hardness high with good dimensional stability the tool steel need to be able to handle a high temperature tempering.
- To achieve the better long-term dimensional stability, add one or more temperings to the heat treatment. You can also add a deep cooling directly after quenching.

Choosing the correct steel grade is key for having good dimensional stability. Avoid specifying with an international standard, as this can cause large variations in the quality of the tool steel. Choose a tool steel with a composition optimized for the manufacturing method used for less alloy segregation and good temper-back resistance. Choose an ESR steel such as Uddeholm Caldie, a PM steel such as Uddeholm Vanadis 4 Extra SuperClean or a conventional ingot cast steel such as Uddeholm Sleipner.

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