Optimal methods of heat treatment of hot work steels

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1. Introduction

Heat treatment of tools from hot work steels is one of the most demanding disciplines in the field. Not in terms of our own processes, which are also supported by the increasingly sophisticated technology of vacuum furnaces, but in terms of optimal service life results. As practical applications are variable, equally variable results are achieved in tool life and it is often very difficult to assess not only the causes but also the consequences.

This is partly due to the repeated defective procedures in the production of the tool - although the procedures are obvious, especially economic pressures still lead to the omission of recommended or even completely essential operations only in order to save costs in the production of the tool.

Despite this situation, we can state today that there are general principles, the observance and standardization of which can gradually increase service life.

2. Material

If we talk about the material, it is mainly a group of materials 1.2343, 1.2344 and then 1.2365 or 1.2367 with increased abrasion resistance. The following applies to all these types of materials:

- the material must have a low sulfur content <30 ppm
- the material must be deoxidized and must have precisely limited amounts of impurities and inclusions
- the material must be produced by ESR or VAC method
- the material must have a defined primary grain size
- the material must have a minimum amount of primary carbides and their even distribution
- the material must have a defined toughness and it must be greater than the minimum allowed
- the material must have a high resistance to thermal fatigue

Therefore, in order for a material to meet these properties, it must have a clear definition of its origin. Therefore, in order for a material to ensure the required tool service life, its structural properties are more important than its chemical composition. The chemical composition of these steels satisfies (except for material changes) almost always, but the structure only sometimes.

One important rule applies - the purchase of poor quality material can never ensure optimal service life results, and its mechanical properties cannot be improved by any, even the most optimal, heat treatment.

The purchase of quality material is a condition, but the process of production and heat treatment can significantly reduce its performance.

3. Initial structure

The initial structure is important for material acceptance. Its definition is given, for example, by the NADCA 207-97 standard for die casting dies, but it can generally be used for any other application, including forging or hot forming tools. This determines A) the tolerance of the chemical composition of the material, B) the annealing structure and its hardness, C) the size and amount of impurities such as sulphides, aluminates, silicates and globular oxides, D) the absence of cracks after ultrasonic testing, and E) impact tests.

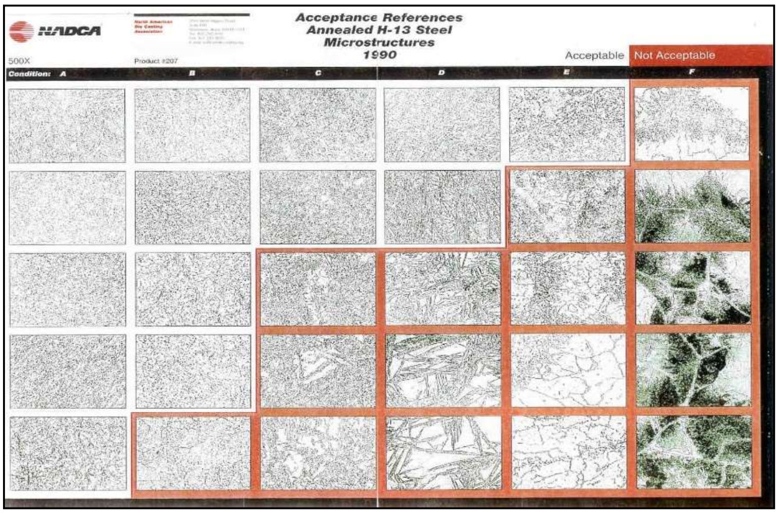


Fig. 1 *Permitted and unpermitted annealing structures according to NADCA 207-9 [1]*

One of the decisive parameters is the fine-grained structure and the intact grain boundaries. These structural defects (primary carbides, oxides, impurities) fundamentally reduce the toughness of steel. E.g. the presence and distribution of primary carbides can reduce toughness up to 10 times compared to the ideal state.

In Fig. 2 is a graph of the relationship between the amount of primary carbides and toughness, and Fig. 3 is the relationship between the amount of thermal fatigue cracks and toughness.

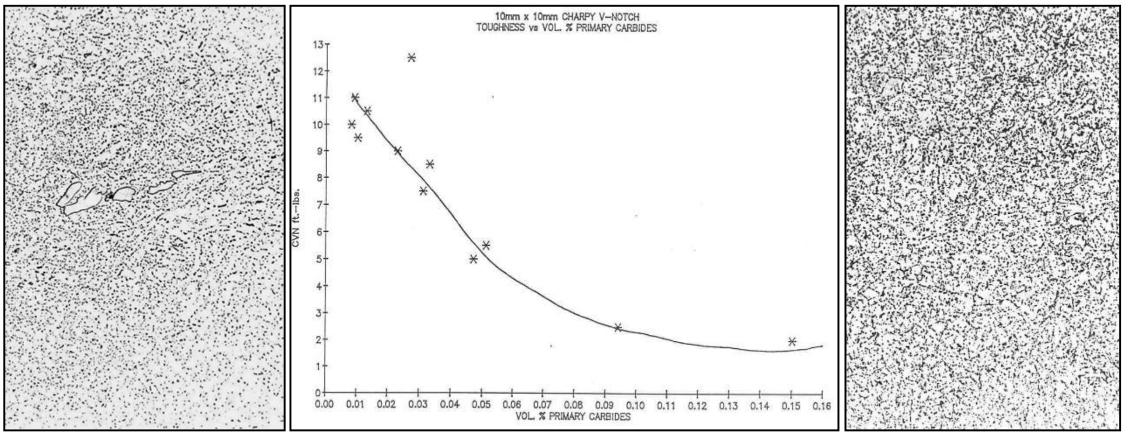
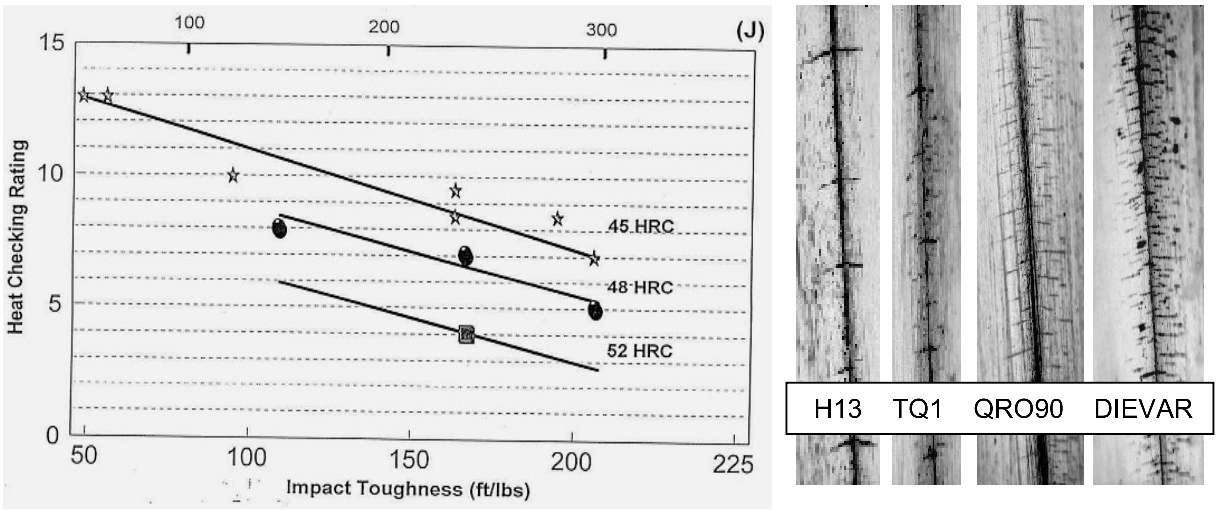


Fig. 2 *- Influence of the amount of primary carbides on the toughness of steel [3]*



Obr. 3 *Influence of toughness on thermal fatigue resistance [3]*

4. Heat Treatment

Heat treatment can affect the resulting properties of the material. The basic problem is that the material must be cooled so fast that carbide precipitation cannot occur during austenite conversion. In Fig. 4 is a typical CCT diagram for material type 1.2343, where in addition to the area of martensite formation, the area of carbide precipitation, perlite formation, resp. bainitu. Therefore, in order for the steel to be well processed, a cooling rate must be chosen that allows the carbide precipitation area to be missed. This speed should be greater than 28 C/minute and this is an essential parameter for the technical equipment of the hardening equipment.

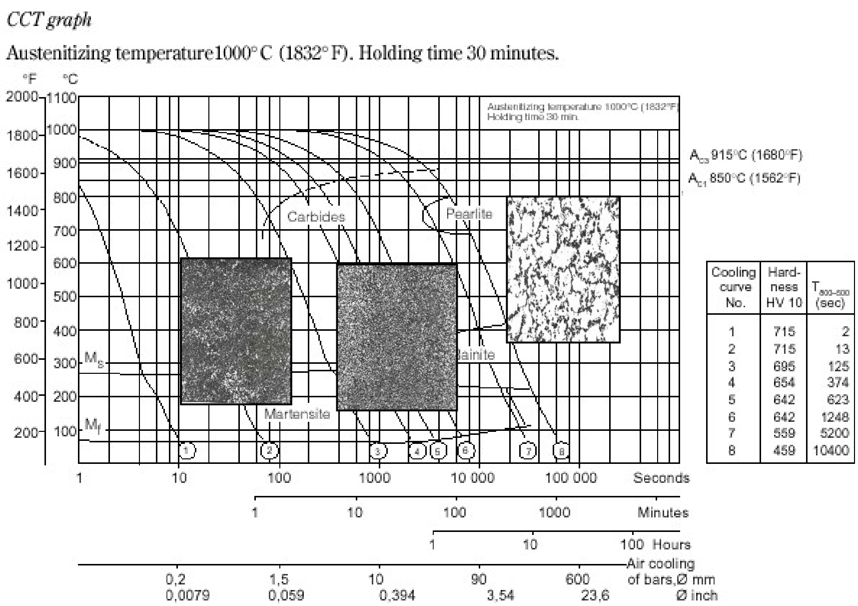


Fig. 4 *- CCT diagram for 1.2343 with different structures according to cooling rate [3]*

Failure to do so may result in the matrix either containing more carbides than is acceptable or, in the worst case, perlite or bainite. Both variants reduce toughness and are unacceptable (see Table 1).

STRUCTURE AFTER QUENCHING	J/cm2
Martenzite without carbides	24-27
Martenzite with fine carbides	20
Martenzite with small amount bainite	20
Martenzite with heavy carbides	16
Martnezite with heavy carbides and portion bainite	9
Martenzite with portion perlite	5

Tab..1 *Impact toughness values for different structures [1]*

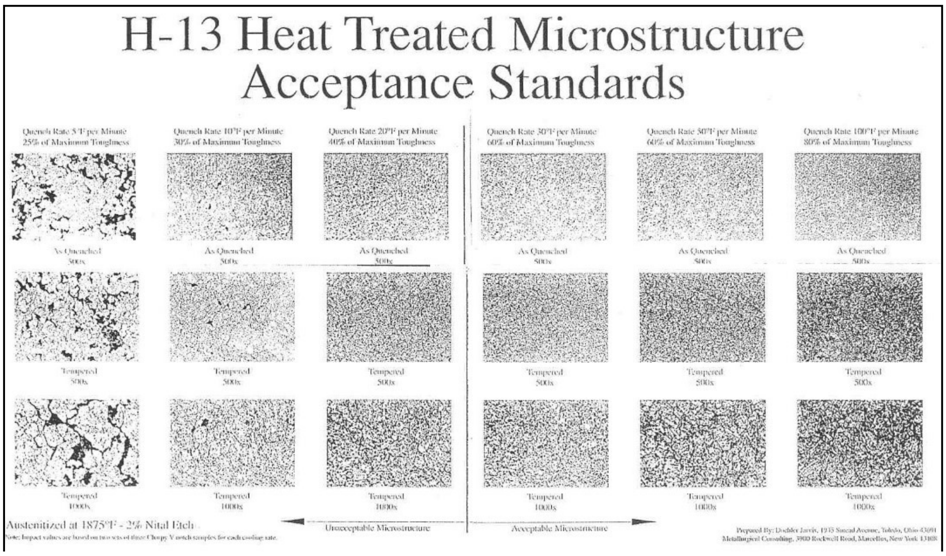


Fig. 6 - *Structures of material H13 (1.2344) after hardening - in the left part when cooling <15 C/min, in the right part when cooling > 30 C/min [1]*

The structures after hardening of H13 steel (1.2344), which are acceptable, are shown in Fig. 6. The required structures can only be achieved if the cooling rates are increased. In vacuum furnaces, this is due to the nitrogen overpressure at which cooling takes place, as well as the furnace design, fan power, cooler etc. It is therefore largely an individual matter of the furnace itself and the results from one furnace cannot be clearly transferred to another. The effect of cooling rate on the formation of cracks from thermal fatigue is shown in Fig. 7, the effect on resistance to tempering in Fig. 8. The speed of 180 C/min corresponds to the ideal hardening of samples into oil, the speed of 25 C/min then overpressure approx. 4 bar.

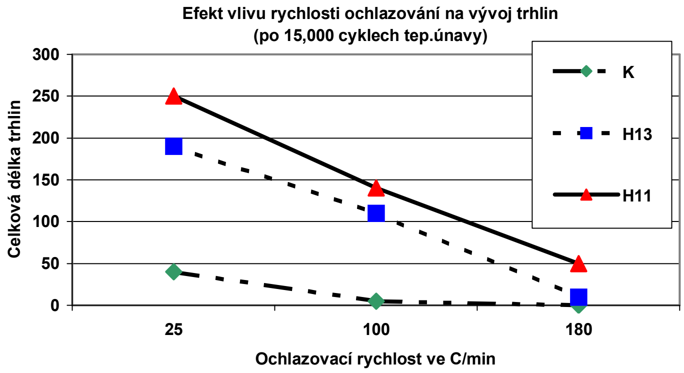


Fig. 7 - *Dependence of thermal fatigue cracking on quenching cooling rate [2]*

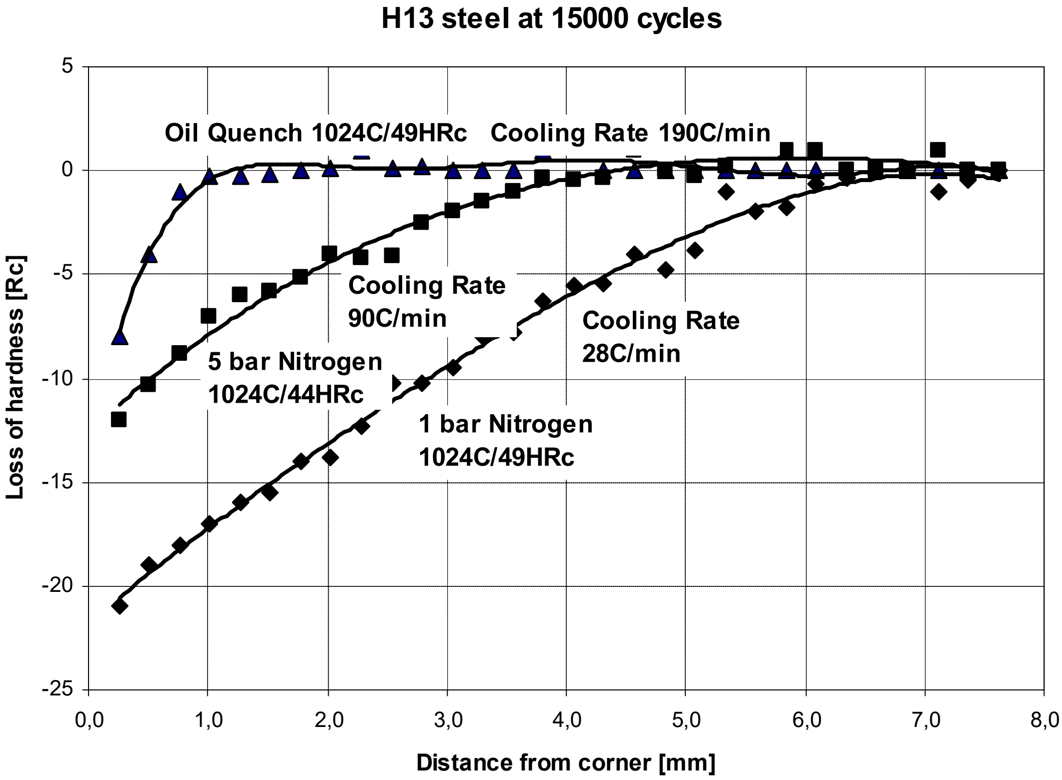


Fig. 8 *- Dependence of steel hardness stability under long-term heat load on cooling rate during hardening measured at different distances from the surface [2]*

The austenitization temperature is determined by the standards or instructions of the steel supplier. The austenitization time is 30 minutes at the core temperature from the time when the thermocouple in the core has reached the prescribed temperature (-) 15 C.

If, during cooling, the difference between the surface temperature and the core is greater than 200 C, or there is a risk of reaching it, an isothermal hold at 450 C is included to reduce the temperature difference.

Therefore, in order to achieve the optimal structure, it is necessary that the parts be tempered 3 times. This requirement is based on the fact that each material has a certain amount of residual austenite after hardening, which is transformed into martensite after the first tempering. However, even this martensite must be tempered twice, so it is necessary to always include the third additional tempering.

5. Conclusion

Optimal heat treatment procedures for hot work steels include other conditions that have not been mentioned. But they all have one goal - to ensure maximum toughness of the material. The production of the tool includes annealing processes to remove stress aftre machining, after electroerosion, after welding, or after testing. All these processes, as well as hardening, must take place under a protective atmosphere or in a vacuum. All processes that could endanger grain boundaries, eg by oxidation, are prohibited.

The material selection process is far more important than the heat treatment process. Even the optimal heat treatment procedure cannot replace what the material is not able to prove. Therefore, all measures of tool manufacturers must be oriented not only to the control of heat treatment suppliers, but above all to their own specifications in the area of steel purchase and its entry control. Only when this process is 100% under control is possible to look for optimal heat treatment conditions.

[1] Nadca Publication 229 – Special Quality Die, Steel and Heat Treatment, Acceptance Criteria for Die Casting Dies

[2] Nadca Publication 308 – Extended Die Life for Aluminum Die Casting, 2009

[3] Corwyn Berger - Extended tool life on die casting, Presentation Brno, 1999