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TEMPERATURE AS A CRITERION FOR CLASSIFICATION OF COLD, WARM AND HOT CRACKING

TEMPERATURA KAO KRITERIJUM ZA RAZVRSTAVANJE HLADNIH, TOPLIH I VRELIH PRSLINA

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- casting
- working temperatures
- quenching
- welding
- cold, warm, hot cracks

Abstract

In this paper the temperature is used as a criterion for the classification of cold, warm, and hot cracks instead of traditional criteria based on the manufacturing process (casting, rolling, forging, welding).

Ključne reči
- livenje
- radna temperatura
- kaljenje
- zavarivanje
- hladne, tople i vrele prsline

Izvod

U ovom radu temperatura se koristi kao kriterijum za razvrstavanje hladnih, toplih i vrućih prslina umesto tradicionalnih kriterijuma zasnovanih na proizvodnom postupku (livenje, valjanje, kovanje, kaljenje i/ili zavarivanje).

INTRODUCTION

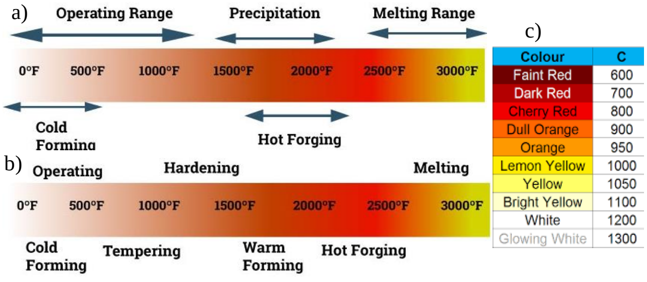
The cracks in metallic products may appear in practically every production process, beginning with casting. Solidification is a process which takes place just after the molten metal is poured into the mould cavity. A crack that appears in this stage of production is known as a hot, and also as a crystallisation crack. In many alloys, while cooling through the elevated temperature region, the versatility of phase transformation processes may occur, leading to warm cracks, but in fact they may be called transformation cracks. During heat-treating processes of many alloys, a kind of transformation process takes place, so these cracks should be classified either as warm or transformation cracks. Finally, if cracks are noticed at or near room temperature, they are classified as cold cracks.

According to the provided forming method, cracks may appear during rolling or forging (e.g., in a hot, warm, or cold state), sometimes during cutting (by turning, milling) or grinding. After (electro) chemical deposition, cracks are usually provoked by localised hydrogen evolution, and they are classified as cold cracks. However, hydrogen may also be found in castings and in some welding processes. The crack appearance is always in direct relation to the applied temperature and/or force (frequently expressed as stress).

In production stages of either ferrous or non-ferrous alloys, a variety of fabrication methods are used, so it is not easy to make a strong classification based on just one level of the processing temperature. For example, the temperature level for warm or hot working, as well as their cracks, is not the same for steel in comparison with titanium and a lot of other alloys. It seems that the recrystallisation temperature is hidden in the analysis, for example, in the occurrence of welding or post-welding cracks. Manufacturers of steel structures are more oriented on steel properties, and less on the character of potentially occurring cracks. Such established criteria are sometimes unavailable for other alloys or fabricating methods. Problems about shape and/or crack length will not be analysed here.

TEMPERATURE RANGES IN PRINCIPAL METAL SHAPING PROCESSES

For further discussion on temperature diversification, some of the main production processes should be observed according to their temperatures. A great deal of those processes must be performed at elevated or high temperatures. Some temperature charts for explaining the temperature level for a particular processing group may be a little bit confusing: Fig. 1a shows the ranges for cold and warm forming and hot forging (meaning other metal working processes as rolling, etc.), including hardening and tempering. Slightly changed diversification is shown in Fig. 1b because warm forming is missing. In both figures, a melting range is designated in yellow colour. Note that in Fig. 1b instead of hardening, the term precipitation is used.



Colour	C
Faint Red	600
Dark Red	700
Cherry Red	800
Dull Orange	900
Orange	950
Lemon Yellow	1000
Yellow	1050
Bright Yellow	1100
White	1200
Glowing White	1300

Figure 1. a) and b): two approaches in temperature charts for diversification of various metal working processes (IQSdirectory.com); c) heat colours and approximative temperature chart for steels.

At elevated temperatures everything is a radiant body, e.g., emits electromagnetic waves in a variety of frequencies (visible in different colours), so the level of heating up a body can be seen by naked eye. For steels, such a colour chart with temperatures is represented on Fig. 1c. However, this is an approximate scheme.

For making castings the metal should be melted and in this state it is highly irradiated. In most welding processes the metal must be melted, visible in yellow or white colour.

MAIN METALLURGICAL PRODUCTION METHODS

Shaping or joining of any metallic product is commonly based on semi-products obtained by casting and other metallurgical methods which might be crucial for understanding problems in further fabrication. The possibility of cracking is the main characteristic in any subsequent process.

Casting and solidification cracking

Casting is the first process in the making of any metallic product. During casting, i.e. solidification, sometimes cracks may appear which could be referred to as hot cracks. This type of crack may occur at the early stage of production of any component made of a ferrous or a non-ferrous alloy.

A typical dendritic structure may be formed after solidification /1-5/, as shown in Figs. 2a and 2b. The castings design may have a large influence on cracking, as shown in Figs. 2c and 2d. During the servicing period, a crack is initiated between dendrites and further expands along the grain boundaries when the plasticity of such a structure is pretty low, which is why this type of structure is often undesired. Impurities along grain boundaries usually show harmful effects on mechanical and other properties of the castings.

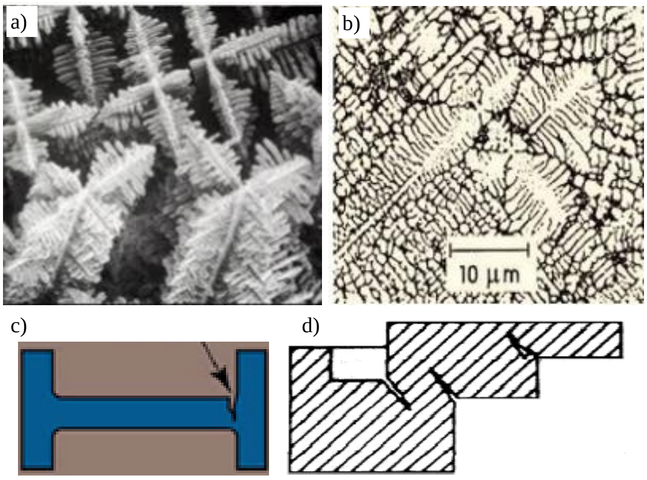


Figure 2. Examples a) and b) of dendritic structure; c) and d) are cracks formed after shrinkage.

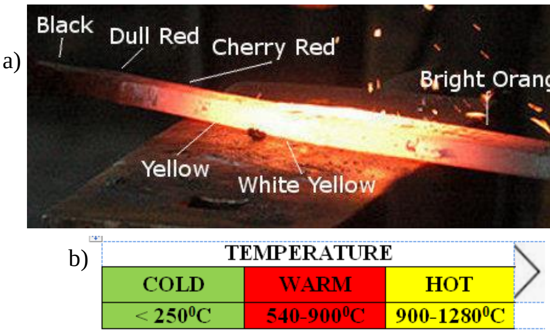
As solidification proceeds, the low melting mixtures, frequently eutectics, are concentrated at the centre of the casting wall and remain liquid, making a liquation or they might be called grain boundary melting when the liquid film is distributed along grain boundaries. The nature of casting cracks in fact is pretty complex because it depends on many properties of an alloy and also on numerous technological factors, one of them being casting design (unrealistic geometry), etc. /2-5/. Thin wall in combination with massive wall castings (usually at corners) may produce a crack just after the molten metal is poured into the mould cavity, Figs. 2c and 2d, when the metal is still at high temperature. For steels and irons, as frequently used alloys, this temperature range is 1450-1250 °C.

The risk for cracking is higher if casting walls are not uniformly cooled when the shrinkage of castings is blocked by the mould. This network of cracks (of irregular shape) may penetrate through the entire casting wall and are possible places for initiating corrosion processes. Many of these cracks can not be seen at the casting surface and are referred to as internal cracks. The term *hot crack* from foundry practice is also known in welding practice with different names, such as: solidification crack, liquation crack, hot shortness, or hot fissuring,

Deformation, temperature, and transformations

Most as-cast products (slabs, ingots) are to be deformed, commonly by forging or rolling. One example is forging, used in the past as an obvious process, and here a sword (thin but long product) is an example with a visible spectrum of colours at forging, Fig. 3a. These colours are helpful to an experienced blacksmith in producing a sword without cracks. Heat treatment follows after forging when cracking must also be avoided.

The diversification of deforming processes, according to temperature and colour, is sometimes described only as cold or hot (two groups), see Fig. 1b. But Fig. 1a shows cold, warm, and hot (three groups). The appropriate temperatures of these three groups are shown in Fig. 3b for plain carbon steels. The alloying elements, however, may have (weak) influence on the colours and appropriate temperatures, so this is an approximate guide.



TEMPERATURE		
COLD	WARM	HOT
< 250⁰C	540-900⁰C	900-1280⁰C

Figure 3. Colours at: a) sword forging; and b) temperatures for principal groups of deforming processes for steels.

Rarely, one can find a closer diversification of forging processes according to recrystallisation temperature, Table 1.

According to strictly metallurgical reactions which may take place in the metal/alloy, and for describing deformation processes, the scheme from Table 2 is more representative.

Table 1. Forging process and recrystal. temperature for steel, /9/.

Deformation	Temperature
Cold	starts at room temperature (315-427 °C)
Warm	below or near recrystallisation (482-982 °C)
Hot	above recrystallisation (982-1204 °C)

Table 2. Temperatures for deformation processes according to recovery and recrystallization temperature, /6/.

Recovery temperature		Recrystallization temperature	
below cold deformation (without recovery)	above semi-warm deformation (with recovery)	below warm deformation (with partial recrystallisation)	above hot deformation

Although this, however, is a valuable approach, in reality for consumers it is a too complex job to determine both, the recovery or recrystallization temperatures for every used material/alloy. From Table 2 it is clear that hot deformation is provided over recrystallisation temperature (T_r, in K). Recrystallisation and recovery processes are pretty well explained in metallurgical literature /3-9/. Some explain that recrystallisation may be achieved during 'semi-solid temperature annealing', as given in /10/, being invalid and can not be accepted.

Cold deformation is performed at low temperatures, below $0.3T_s$, (T_s is solidification temperature, K), or below recovery temperature, /6/. During the cold forming strengthening mechanism of a material and high degrees of deformation are applied, then cracks may appear in the working material or in the deforming tool, or in both. Cold deformation needs a higher loading but provides a shiny metal surface. After reaching a limiting degree of deformation, the intermediate annealing, at temperatures above recrystallisation, should be applied. It seems that cold deformation mechanisms are not too complex for understanding.

Semi-warm deformation occurs during recovery, but below recrystallization temperature. This type of deformation is rarely provided in practice, e.g., in producing of tungsten wire by drawing. In other cases, such as drawing of wires or tubes, it is always done at room temperature.

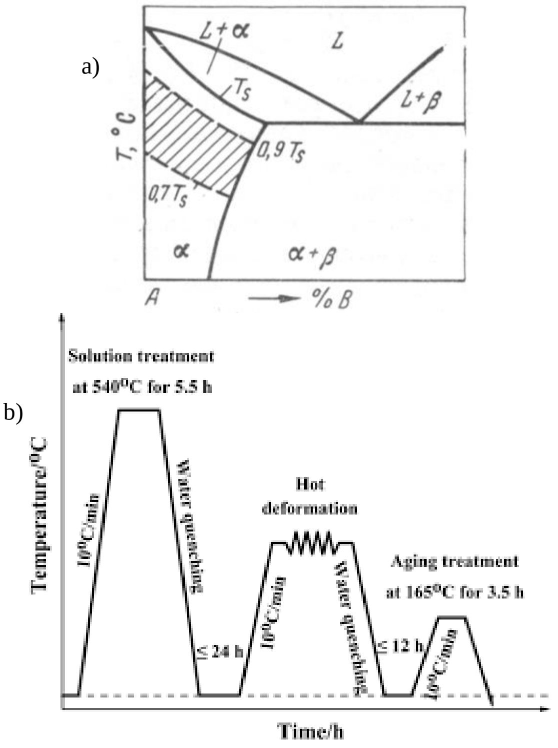


Figure 4. Temperature regimes for hot deformation at: a) a common phase diagram /7/; and b) for an aluminium alloy, including solution and ageing treatments.

Warm deformation is preformed at elevated temperatures, compared to cold or semi-warm deformation, at (0.3-0.6)T_s, when the recrystallization only takes place partially, and for this reason it can sometimes be named semi-hot deformation. An important advantage of warm deformation is in lower applied loads, scaling, and decarburisation in comparison to hot deformation. In discussions on steel production, one can find that warm deformation begins at 900 °C, (even at 1000 °C) and ends at 600 °C. It seems that such an empirical way for defining the temperature interval of warm deformation is just undefined, perhaps confusing it with hot deformation.

Hot deformation usually begins at $0.9T_s$, and up to $0.7T_s$, principally shown in Fig. 4a, and in some references one can find $0.6T_s$. During hot deformation the complete recrystallization is achieved. Both, the start, or end of hot deformation should be controlled /5-8/, for one hypothetical alloying system shown in Fig. 4a.

To achieve successful hot deformation, the soaking must be well done, as shown in the case of some aluminium alloys when after soaking is provided, quenching in water is performed, and in less than 24 hours hot deformation follows, Fig. 4b. For hot deformation, it is desired to be employed at a monophase region, but if an alloy at those temperatures has a multiphase structure, it is clear that achieving a single phase is not possible, as in many tool steels, etc.

For all kinds of deformation processes, the cooling rate and other process parameters, with special emphasis on deformation rate, may influence the obtained properties.

Cooling, quenching, tempering, or grinding cracks

Cracks may be created during sharp cooling regime, e.g., quenching or grinding, as a result of applying high temperatures and involved stresses. Quenching is provided from warm or hot state. The risk of cracking grows with the increase of quenching temperature and other influencing factors. The martensitic transformation usually produces high stresses, and even cracks. Tempering, as an obvious process, is provided after quenching, but in many tool steels, this operation must be provided immediately after quenching, otherwise the entire tool will be full of cracks, and even damaged. If the product with cracks undergoes tempering, especially in an oxidising atmosphere, then such cracks will be oxidised. All of these cracks are irregular in shape. The fact is that cracks may appear in some steels if they are reheated in the interval 500-700 °C. In many papers, these cracks are not classified. Based on the criteria shown here, this is a warm crack, from a specific metallurgical reason - low melting mixture.

Another specific factor, not yet widely spread, is represented by so-called subzero (or deep freezing) treatment. It is used for high carbon, high alloyed tool steel and in the aerospace industry (on other alloys), for completing the unfinished transformation during quenching. For steels, it is of interest to complete the transformation of retained austenite into martensite, as well as to stabilise the dimensions. Danger for crack appearance exists during the quenching, similar to subzero treatment, /11/. Subzero treatment temperatures (SZT) lie between -70 to -196 °C (liquid nitrogen, rarely at liquid helium lower temperatures). This treatment is always followed by tempering and must be provided with controlled cooling and heating to tempering temperatures (150 to 180 °C for steels). If tempering after deep freezing is not done, the risk for cracking is extremely increased, even if cracks had not occurred in previous treatments.

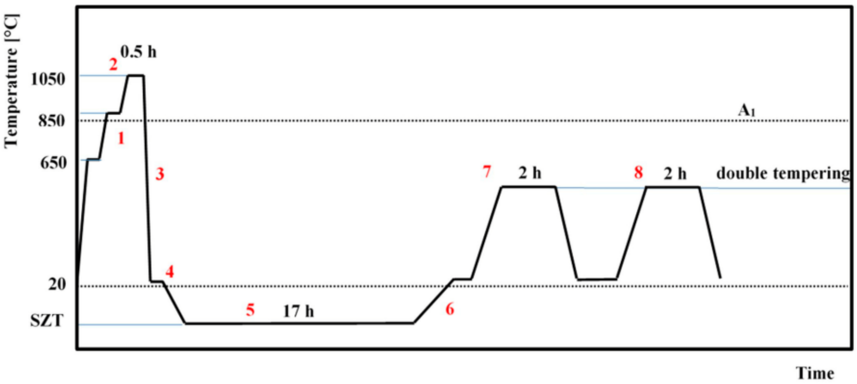


Figure 5. T-τ diagram for heat treating (quenching + SZT + double tempering) for die steel, /11/.

The tempering regime is a time consuming process, Fig. 5, which can be explained by low diffusion rate at subzero temperatures. Every fast cooling or heating rate from the subzero regime will produce a crack.

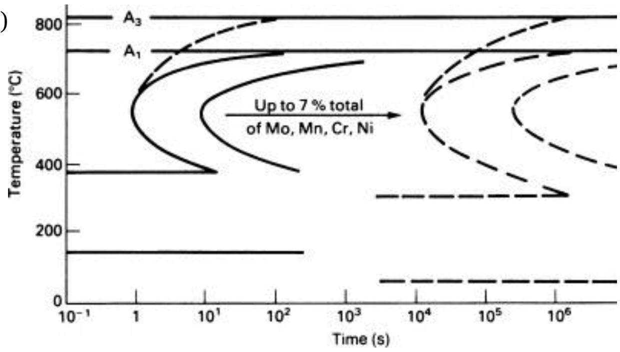
Grinding is the last operation in manufacturing of many precise mechanical components, so cracks appearing at the final stage of manufacture are never welcome. During grinding, there are visible white or red sparks, and are a reliable sign that metal surface is overheated under pressure. If during grinding the surface is overheated, it is followed by fast cooling, and such a surface is quenched. Such cracks also show irregular shape. Grinding is performed at room temperature, but grinding cracks should be considered as warm or hot cracks, depending on the heating and cooling.

Alloying elements in TTT and CCT diagrams for steel

During heat treatment, in fact during cooling, some precipitation processes occur in the alloy, as shown in Fig. 1b. During heat treatment of metals well established principles of cooling exist as an isothermal cooling (temperature time transformation - TTT) diagram and a continuous cooling (CCT) diagram. Alloying elements influence many properties, and their effects on transformation temperature and cooling curves in appropriate diagrams are described in Fig. 6. Most alloying elements retard the $\gamma \rightarrow \alpha + Fe_3C$ reaction during cooling, principally shown in Fig. 6a, and one example is shown in Fig. 6b.

During both cooling regimes, the cracks may be found and influence of an alloying element (for example as molybdenum in steel) on stopping the cracks appearance in such treated steels will be explained here. The most critical regime of cooling is during the martensite formation, so in many cases the better cooling regime is the one which produces bainitic transformation.

a)



b)

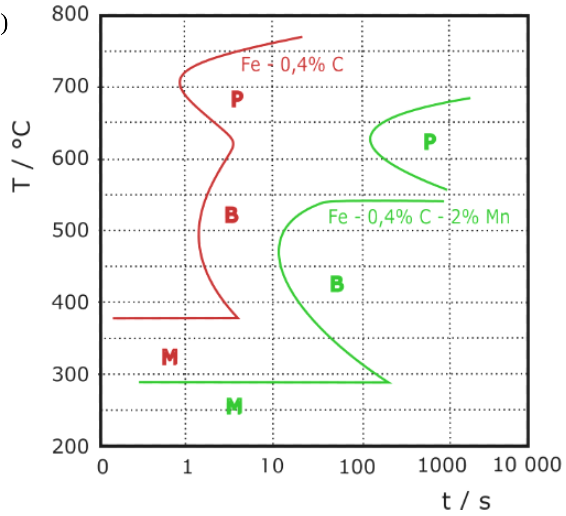


Figure 6. Effects of some alloying elements: a) TTT diagram for plain carbon steel (0.4 %C-left curve in b); and b) CCT for the same steel alloyed with Mn (0.4 %C + 2 %Mn-right curve).

Precipitation of some intermediate, intermetallic phases or compounds

Critical cracking may take place during quenching, as shown, but also in the formation and/or precipitation of some intermediate, intermetallic phases, or compounds at temperatures shown in Fig. 7, in the TTT diagram, /12/.

Transformation of these phases/compounds may influence increased tempering brittleness, but it does not mean a crack is formed immediately. Certain alloying elements affect grain refining, and such steel is less prone to quenching or welding cracks.

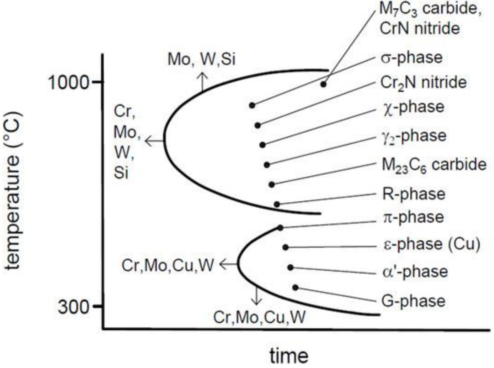


Figure 7. Precipitation temperatures for important intermediate and intermetallic phases in steel.

Simultaneous deformation with heat treating and thermocycling of steels

In the last decades, some methods for instantaneous deforming and heat treating have been improved. Temperature as a criterion for starting or finishing different types of processes, mentioned previously, is given in Fig. 3a. Depending on applied deformation and cooling regime, a variety of shapes and sizes of recrystallized grains during steel rolling could be represented in the CCT diagram, Fig. 8a.

An interesting overview is given in Fig. 8b, which compares cycles of conventional rolling, simultaneous deformation and cooling and reheating in order to achieve the desired deformation temperature. Two variants of thermomechanical rolling (TMR) with followed normal air cooling (AC), and TMR with water cooling and accelerated air cooling (AcC) are shown in Fig. 8b.

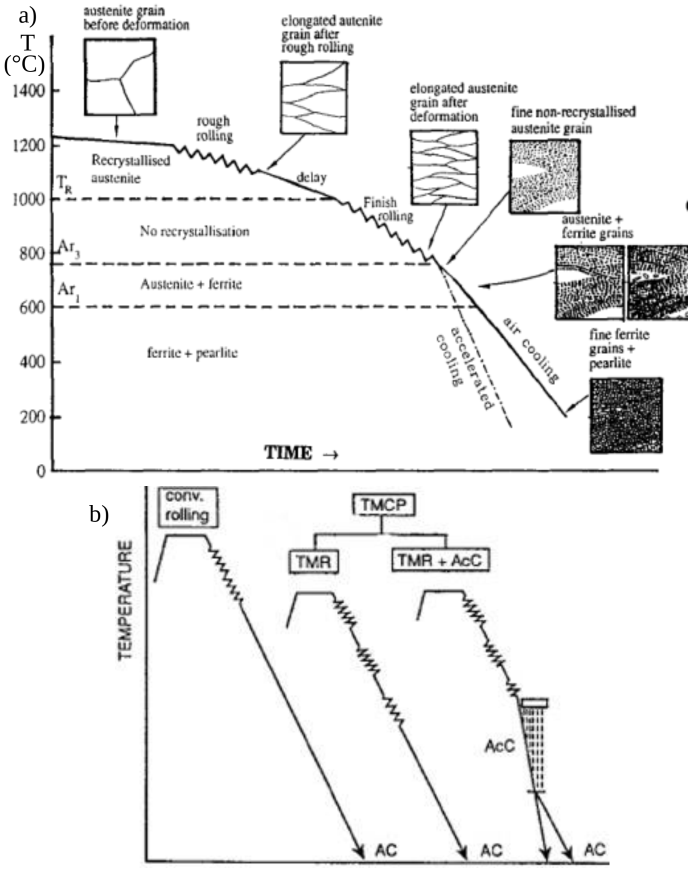


Figure 8. a) Sketch of recrystallized grain sizes after hot and warm steel rolling in CCT diagram; and b) other types of thermomechanical treatment regimes.

The most important parameters for every TMR are: austenitizing temperature, soaking time, rates of cooling and heating, number of thermocycles, temperature of the last cycle, etc. Alloying elements may result in changing of the solubility lines and temperatures, and also in decreasing the plasticity, i.e. formability, and many other properties, including cracking.

According to diagrams from Figs. 8a and 8b, the processing temperature is always decreasing, but deformation and heat treatment are provided at a constant temperature, and heating up, i.e., a cycling temperature, is forming some possibilities, as shown in Fig. 9a. As can be seen from Fig. 9a, there are 4 possible types for thermocycling of a steel:

- with phase transformation through interval below A_{c1} and above A_{c3};
- particular transformation around A_{c1};
- only transformation below A_{c1}, and
- only transformations above A_{c3}.

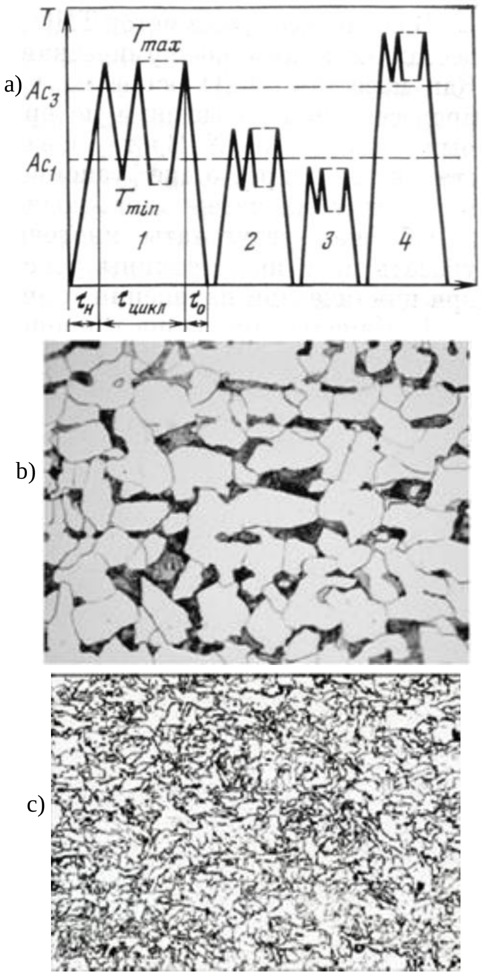


Figure 9. a) Possible principal temperature - time regimes for thermocycling of steel /14/; structures after b) conventional, and c) thermomechanical rolled same plain carbon steel.

Verification of obtained structures after two different regimes is evident. Figure 9b shows the structure under conventional heating, and Fig. 9c the refined structure after TM hot rolling, in both cases without cracks. Steel treated on TMR shows improved mechanical properties, good cold formability, frequently with no cracks, thanks to a fine-grained structure.

Such kind of thermocyclic treating is available due to isothermal rolling at pearlitic or bainitic zones, for one medium carbon-chromium structural steel shown in Fig. 10 (from: Atlas of Isothermal Transformation and Cooling, Pittsburgh, 1959). In these zones, it is usually possible to achieve acceptable properties, without cracks occurring in the structure. Application of such regimes still represents a rather complex job in practice, because when the rolling piece is constantly cooling, reheating is necessary, as can be seen from the same figure, showing the cycling temperature.

Each of those regimes must be practically approved for avoiding crack appearance. Rolling temperatures as shown are not obvious for every steel, it means they may slightly change depending on the chemical composition in accordance to the projected or demanded properties of the chosen steel type.

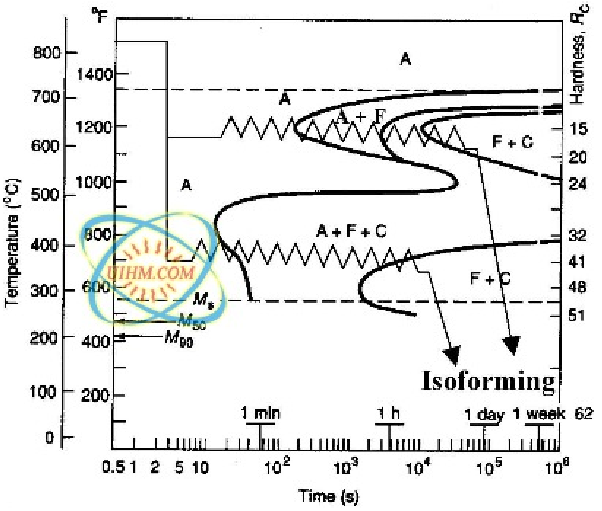


Figure 10. Isothermal rolling of 4340 (ASTM) steel sheet in the pearlitic and bainitic area, /10/.

CRACK CLASSIFICATION DUE TO TEMPERATURE

When temperature is chosen as a criterion for crack diversification, most sources had adopted two types: cold or hot cracks /14-16/. But a more accurate or reasonable diversification of cracks (formed during casting, deformation, welding or heat treatment) also based on temperature may be better classified into three types: cold, warm, or hot. According to previous explanations on the kinds of deformation, the diversification of cracks here is based also on temperatures of recovery and recrystallization, Table 2. As follows:

- when the crack is formed below the recovery temperature $0.3T_s$, that crack is cold;
- anyhow, if the crack is formed at a temperature range of $(0.3\text{-}0.6)T_s$, i.e., between temperatures of recovery and recrystallization, then it is a warm crack; and
- a hot crack is formed above recrystallization temperature, up to the melting/solidification temperature (may be considered as a particular type of crack).

Cold cracks are mostly formed during cold deforming, at temperatures below recovery temperature. For common people, it is hard to accept that if the metal product was heated, for example, at 400 °C, this is a cold state. Cold cracking, in the case it occurs during cold deforming, is frequently the consequence of applying a too high temperature reduction degree. This type of crack is narrow, sharp, usually not oxidised, with a relatively clean surface. Cold cracks are often encountered in castings at cross sections between thin and thick walls, and similar situations may be found in welds, when they are rapidly cooled from the melting pint to near-room temperature. The origin of this cracking is also in correlation with the high concentration of hydrogen.

In electrochemical deposition technologies of many metals, considerable amounts of hydrogen are typically released, which are often the main reason for cold cracking of steel parts treated in this way. High carbon and chromium content in steel, also with high cooling rates, creates conditions susceptible to cold cracking. The high level of residual stresses, particularly of the tensile type, is also an important contributing factor.

In welding engineering practice, sometimes cracks below 450 °C are identified as cold, which is not in agreement with previous explanations for the role of recovery temperature. A warm crack is initiated at temperatures above recovery temperature, but lower or partially at recrystallization temperature.

The diversification of a particular crack according to the presence of intermediate, intermetallic phases or compounds is a demanding task. Some of those phases/compounds are hard, but brittle, and their occurrence does not immediately produce cracks. From that point of view, some temperature intervals should be controlled, or even avoided. For further understanding of their nature or transformation mechanisms, a solid knowledge of physical metallurgy and heat-treatment principles is required.

Hot cracking is initiated during hot deformation, as a result of inadequate application of deformation demands, for example, speed, even when the working temperature is well chosen. Hot cracks are not so frequent in deformation processes but may be found in practice. An example of hot cracks formed during heavy steel forging with inadequate deformation rate is shown in Fig. 11, or the piece was not correctly heated-up for hot deformation. Forgings like this possess pretty simple geometry, but one can imagine what kind of cracks are possible in forgings with more complex geometry. This example of hot deformation with working parameters should be carefully considered. The hot crack is commonly oxidised, and is wider than a warm, or a cold crack. In most of the literature /4/, one can find that a hot crack is sometimes referred to as a warm crack. However, it can not be an exact explanation. The recovery and recrystallization mechanisms are explained in /2, 3, 7/.

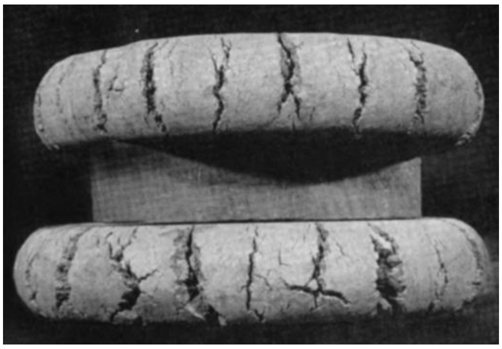


Figure 11. Hot cracking in a high-carbon and chromium steel after hot forging.

WELDING CRACKS

Previously explained methods for production of sheets, bars, or profiles (by casting, forging, rolling, and quenching) represent good examples of welding defect types, which can occur. Thus, before the start of welding, the principal properties (and structures) must be well known in order to avoid crack occurrence, or even structural damage as a whole.

There are situations when some casting defects may be repaired by welding, but this is only a portion of problems in welding.

Not all welding cracks are identical to cracks occurring in casting, deforming, or heat treating, but they are pretty similar, indeed. Welding cracks may occur in the fusion zone, but also in the heat affected zone (HAZ). Taking into account the lack of skill and/or experience, welding cracks are frequently monitored and discussed as a separate group of cracks, which have no connection to real metallurgical phenomena. In welding practice, it is not unusual that cracks, detected just after the metal is melted, solidified, or in the post-weld period, are separated into a category of welding cracks, instead of solidification or transformation cracks.

When an analysis of cracks is provided according to their origin, in terms of the manufacturing method - in this case welding - one must keep in mind that all previous manufacturing methods and structures must involve the analysis of welding crack formation. The nature of hot welding cracks is very similar to cracks formed in castings - only the geometry is dissimilar. If the supply of the liquid weld metal to fill spaces between the solidifying weld metal is not enough, then shrinkage strains are created, and frequently afterwards a crack is formed. Such a crack may be created when welding is still in progress.

In welding practice, one can only find two existing types of cracks: cold and hot /13-15/. According to the nature of welding practice and crack location (inside or near the weld), it is more accurate to accept that there are three types: cold, warm, and hot welding cracks. According to such diversification, the cold welding crack in steel occurs at near room temperature, which is according to the criteria applied here just below recovery temperature (not near 450 °C). Cold cracks typically occur up to 48 hours after welding. Such cracking closely related to high hydrogen contents in the weld. Further, a warm weld crack appears at temperatures below or close to recrystallization temperature. So, if the welding crack in steel is detected at, e.g., 650 °C or lower temperatures, than it should be a warm, but not a hot crack. The specific type of warm crack is the so-called liquation tearing (LT), as a result of the development of low melting (eutectic) mixtures along grain boundaries. This type of cracking is positioned at the HAZ, as seen in Fig. 12. The temperature character of this crack can designate it only as a warm crack. It must be pointed out that these cracks are of metallurgical character, /17/.

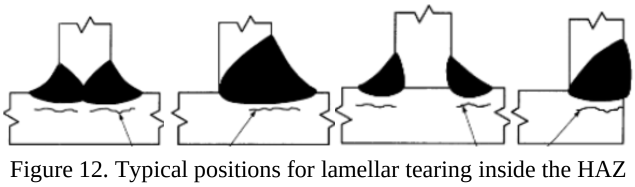


Figure 12. Typical positions for lamellar tearing inside the HAZ in massive weldments.

Finally, if the crack in steel is detected at 900 °C and above melting temperature, then it must be a hot welding crack, including a solidification crack. This approach needs strict temperature measurement, not subjective assessment.

When characterising weld cracks, everyone should be very careful, because the base material is produced by cold, warm, or hot deformation and/or different means of heat treatment, all of which lead to the formation of a variety of structures. In other words, it means that the metallographic structures and other properties should be known before the start of welding, especially for responsible structures.

Many sheet metal products are continuously annealed or galvanised /18/, so this fact (including coating type and depth, hydrogen absorption, etc.) must be taken into account when analysing cracks for any further application of shaping or joining processes.

CLOSING COMMENTS

The problem of cracking in reality represents a very complex field of questions and problems in metallurgy and materials science. The temperature classification of cracks is frequently poorly explained or termed, introducing confusion at times. There is no doubt that casting, metal working (deformation), and/or heat treatment of metals bring on similar influencing parameters: temperature and stress. The level of true stress present is more often than not measured in practical situations, thus the temperature could be used as a representative criterion for crack occurrence, as an easily measurable value.

It seems that criteria for crack appearance based on recovery, and recrystallization temperatures might be unacceptable as a simple method for many engineers, but this is, without doubt, a reliable metallurgical criteria and approach, that does not include any subjective feeling of what is a cold, warm, or a hot state.

Criteria for crack appearance, generally, are not strictly established, because for steels it is suggested /14-16/ that cold cracks form below 450 °C, but it is hard to accept this temperature as a cold state. Also, it is widely accepted that warm deformation of steels takes place at 600-1000 °C, while the hot deformation is above 900 °C - confusing, isn't it!? A similar confusing classification can be found when crack types are divided into two groups, cold and hot /14-16/. Such classification is very simple and may be accepted only as a quick approach and seems to be based on a subjective feeling. The confusing explanations of existing two groups of cracks frequently could be found also in the welding terminology. The problem of registering the recovery and/or recrystallization temperature would not represent a serious or unsolved task.

A more reliable classification here is based on recovery and recrystallisation temperatures, according to which there are cold, warm, and hot cracks, regardless of whether the metal/alloy in question is ferrous or non-ferrous, and are defined as follows:

- when a crack is formed below recovery temperature $0.3T_s$, such a crack is cold;
- but, if the crack is formed a temperature range of $(0.3\text{-}0.6)T_s$, between recovery and recrystallization, then it is a warm crack; and
- a hot crack is formed above recrystallization temperature, up to melting/solidification temperature.

In literature sources, one can find following explanations and conclusions: the cold crack may already exist in sheets during warm deformation, or a warm crack may exist in hot rolled sheets! It is clear that such non logical explanations are sometimes present in existing welding or similar terminology. Those problems, in essence, are metallurgical and can not be based only on the welders' experience, knowledge, and/or interpretation, but on metallurgical principles only.

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