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Possibilties of further increasing the hot workability of ledeburitic tool steels

Možnosti nadaljnjega izboljšanja vroče preoblikovalnosti ledeburitnih orodnih jekel

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Abstract

Ledeburitic tool steels are characterized by variable and essentially lower hot workability in comparison to other steels. In this contribution importance of selecting of appropriate values for some relevant process parameters in ledeburitic steels production, i.e. casting temperature, cooling rate at solidification and soaking temperature needed for improving of their intrinsic hot deformability, is given. Inappropriate selection of casting temperature and cooling rate results in precipitation of unusual eutectic carbides which decreases hot workability of these steels. With selection of appropriate soaking temperature a temperature range of safe hot working can be extended.

Key words: ledeburitic tool steels, process parameters, carbides, hot workability

Izvleček

Za ledeburitna orodna jekla je značilna variabilna in zelo nizka vroča preoblikovalnost v primerjavi z drugimi jekli. V tem prispevku je prikazana pomembnost pravilne izbire vrednosti nekaterih relevantnih procesnih parametrov pri izdelavi teh orodnih jekel, tj. pravilna izbira vrednosti za temperaturo litja, hitrost ohlajanja med strjevanjem in temperaturo ogrevanja za izboljšanje vroče preoblikovalnosti. Nepravilna izbira temperature litja in hitrosti strjevanja vodi do izločanja za ta jekla neobičajnih evtektičnih karbidov, kar znižuje vročo preoblikovalnost. Z izbiro pravilne temperature ogrevanja lahko precej razširimo temperaturno področje varnega preoblikovanja.

Ključne besede: ledeburitna orodna jekla, procesni parametri, karbidi, vroča preoblikovalnost

Introduction

Surface cracking during hot deformation of ledeburitic tool steels reduces mechanical properties and consequently their profitability. These tool steels have high hardness, wear resistance as well as high tempering resistance on one hand, and high flow stresses and low hot deformability on the other hand. Decreased hot deformability of the tool steels is attributed to type, size, shape, distribution, fraction of eutectic carbides and/or other phases and their melting points, grain and carbides growth at upper limit while precipitation of secondary carbides (fraction) and decreased recrystallization rate at lower limit of temperature working range. Increased hot workability in temperature range of 1 020–1 070 °C is attributed to combination of high recrystallization rate, low fraction of precipitated secondary carbides and relative low grain growth rate in this temperature range[1–5].

Occurrence of cracks on most exposed areas of workpiece are related to areas where similar conditions related to upper and/or lower limit of temperature working range prevail, i.e. areas with accelerated cooling, areas with higher value of accumulated strains where also decreased recrystallization rate with presence of higher tensile stresses simultaneously takes place, furthermore areas of workpiece which are due to combustion conditions in furnace heated on higher temperatures, etc. Thus areas, where combination of previous mentioned conditions prevail, are more exposed to cracking. This additionally suggests that hot deformability of ledeburitic tool steel should be considered as a complex problem. Publications in the literature with regards to hot deformability of tool steels are predominately of a partial nature thus all reasons for unexpected occurrence of cracks are not sufficiently explained in available literature so far. Furthermore modern practice proves that previous processing parameters significantly influence the hot deformability and thus this cannot be considered as a constant value. During heating, soaking and hot deformation various processes take place: decay (decomposition) of carbides, formation of new carbides, growth and dissolution of carbides, etc. Thus depending on variation of process parameters and of chemical composition, that consequently influences the processes related to carbides, shifting of decreased deformability at both limits of temperature working range to higher and/or to lower temperatures can occur[5–11].

In this contribution importance of proper selection of casting temperature, cooling rate and soaking temperature on hot workability of ledeburitic tool steels are presented. In the study M42, W.Nr. 1.2690 and D2 tool steels were included.

Description of applied tool steels and experiments

Applied tool steel

The proposed new approach will be illustrated with particular results obtained in thermo-mechanical processing of ledeburitic tool steels, i.e. M42 (super HSS) and W.Nr. 1.2690. All these steels contain C and carbide-forming elements, i.e. Cr, W, Mo and V (chemical compositions are given in Table 1). The microstructure of these steels consists of a martensitic matrix in which the ledeburitic and secondary carbides are inserted. In Figures 1a typical microstructures of ledeburitic tool steels for as-cast initial state are presented.

An optical microscope (OM, Carl Zeiss AXIO Imager.A1m) and a field-emission gun scanning electron microscope (FE SEM) in combination with an attached EDS (INCA x-SIGHT LN2 with INCA ENERGY 450 software) and EBSD (INCA CRYSTAL 300) analytical tools were used to observe the microstructures and to determine the type of carbides.

Table 1: *Chemical composition of applied tool steels in mass fractions, w/%: M42, W.Nr.1.2690 and D2*

	C	Si	Mn	Cr	Mo	V	W	Co
AISI M42	1.09	0.26	0.25	3.81	9.32	1.09	1.40	8.20
W.Nr. 1.2690	1.17	0.24	0.26	11.3	1.35	1.48	2.24	–
AISI D2	1.54	0.32	0.31	11.82	0.79	0.95	0.10	

Laboratory and industrial experiments for selection of appropriate process parameters

The influences of the selected casting temperature on hot workability, influence of cooling rate on obtained microstructure and selection of appropriate soaking temperature for selected initial microstructures were studied combining laboratory and industrial experiments. The industrial investigation of the hot workability involved studies of the influence of the casting temperature, the cooling rate and the soaking temperature on the initial microstructure as well as occurrence of cracking during the hot forging and hot rolling of ingots and billets. Laboratory hot compression tests for selecting of appropriate soaking temperatures were carried out on Gleeble 1500D thermo-mechanical simulator. Appropriate soaking temperature was determined individually for each of three different as-cast initial states (obtained at three different cooling rates) applying special procedure. The criterion for the assessment was the appearance of cracks on the compressed specimen's surface at appointed strain, strain rate and soaking time and the corresponding microstructure of the deformed cylindrical specimen with initial dimensions $\Phi = 10$ mm × 15 mm. The procedure was repeated from the initial 1 200 °C and at decreasing temperatures until the compressed sample exhibited a crack-free surface. A detailed description of this procedure for determining the appropriate soaking temperature is given in[1]. The hot workability of selected tool steels was verified in industrial conditions using previously laboratory determined appropriate soaking temperature and then compared with a too-high temperature.

Casting at various temperatures and testing of hot workability

Results of influence of casting temperature on hot workability will be given at forging of 1.2690 tool steel. Hot forging of ingots with $\Phi = 143$ mm, that were cast at a too-high and at appropriate temperature, respectively, were carried out and appearance of internal cracks in the central region of the forged and rolled billets were investigated.

Laboratory estimation of appropriate soaking temperature

Importance of selection of appropriate soaking temperature for initial as-cast microstructures obtained at various cooling rates; i.e. at cooling rate of 0.25 K/s and 0.16 K/s, on hot workability will be presented for M42 tool steel. Namely, at ledeburitic tool steels the cooling rate strongly influences the obtained microstructure, selection of appropriate soaking temperature and consequently also the hot workability. By applying the previously described procedure (detailed description is given in[1]) for hot compression test on Gleeble 1500D appropriate soaking temperatures for each initial as-cast microstructure were assessed. After laboratory assessment of appropriate soaking temperature this procedure was checked in industrial conditions, i.e. at hot rolling of ingots and continuously casted billets.

Results

Influence of casting temperature on microstructure and on hot workability

During the ultrasonic testing of the soft-annealed billets $\Phi = 143$ mm from the 1.2690 tool steel, hot-forged from ingots that were cast at too-high temperature, for some billets or parts of billets internal defects were detected in their central region. The temperature of heat at the end of the vacuum treatment was 1 512 °C, which was recognized as being a too-high temperature. Figure 1a shows microstructure of carbide stringer perpendicular to the forging direction in the central region of a hot-forged and soft-annealed billet, which consists of spheroidised carbides, a larger quantity of ledeburitic carbides (which is unusual for this type of steel), microporosity and ferrite. Detail of carbide stringer is shown in Figures 1b, where beside carbides M_7C_3 and $M_{23}C_6$ which are usually present in these types of tool steels, also MC and M_6C carbides were found. All these carbides were confirmed by combined EBSD and EDS analyses. Inspection of microstructure also showed larger eutectic colonies with larger eutectic carbides, especially in the centre of the ingot, and consequently in thicker carbide stringers in the microstructure after plastic deformation. Such kind of morphology is a consequence of too-high casting temperature that resulted in more intensive segregations of vanadium and tungsten and the precipitation of their carbides. Despite enormous carbide segregations in the ingot core the deformed steel did not crack during the radial hot forging. But during the subsequent hot rolling of the billets in a profile of $\Phi = 61$ mm, where tensile stress states are predominately present, the yield was approximately 15 % lower in comparison to charges that were cast at appropriate temperature. It is worth to mention that the microstructure which was taken from the centre of forged and rolled billet (ingot previously casted at appropriate temperature), consisted of ferrite, spheroidised carbides of type $M_{23}C_6$ and smaller ledeburitic carbides of type M_7C_3 while no MC and M_6C carbides were found.

A detailed investigation of the internal cracks in the central region of the billets with the optical microscope, FE SEM and the combined EDS and EBSD analyses of microstructure revealed that cracks did not follow the stringers consisting of the usual M_7C_3 and $M_{23}C_6$ types of carbides. Namely, cracks occur along the stringers that contain previously mentioned carbides that are unusual for this type of tool steels and are not present in case of appropriate casting temperature; i.e. small vanadium eutectic carbides and small complex eutectic carbides (see Figures 1c–d). The complex carbides are composed of small vanadium carbides of type VC surrounded by M_7C_3 in the central part and of precipitated $M_{23}C_6$ in the outer part. Thus in the regions where the carbide segregations are present (vanadium and complex carbides), the tool steels will crack during hot deformation.

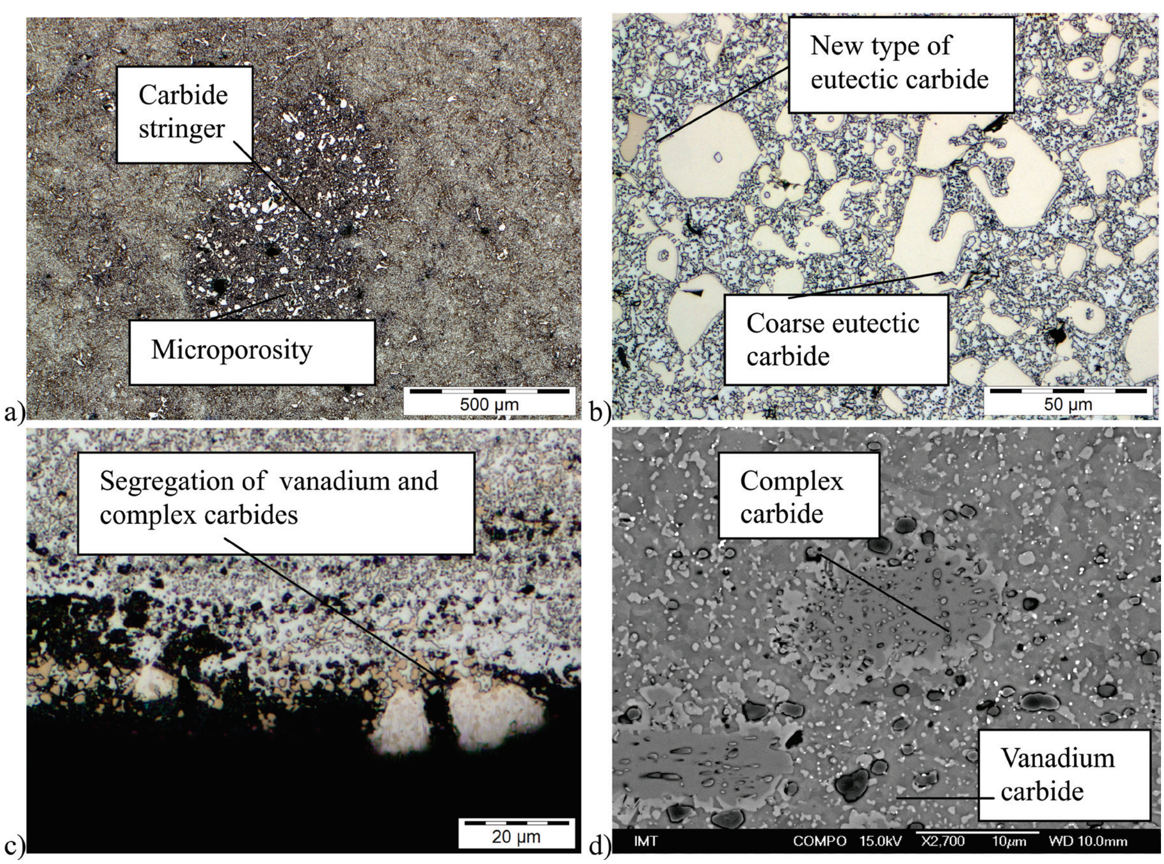

Figure 1: *The microstructure of a soft-annealed forged billet of Φ =* 143 mm *from W.Nr. 1.2690 tool steel (perpendicular to the deformation direction): enormous carbide stringer in the centre of the billet, OM (a); larger eutectic carbides and a new type of carbide in the base microstructure from spheroidised carbides and ferrite in the carbide stringer, OM (b); appearance of cracking in the central part of the soft-annealed rolled billet steel along unusual segregations of "yellow-coloured" vanadium carbides, OM (c); segregation of vanadium and complex carbides at cracks (d).*

Appropriate soaking temperature and hot workability for various initial as-cast microstructures

Influence of soaking temperature on hot workability for microstructures in casting ingot

In cast ingot a variety of microstructure is usually obtained since each selected spot on ingot cross-section towards ingot centre different cooling rate. Thus for M42 tool steel and cooling rate of 0.25 K/s a microstructure shown in Figure 2a had obtained; the fine lamellar as-cast microstructure with precipitated M_2C type of carbides. On the other hand at cooling rate of 0.16 K/s beside M_2C type of carbides also for this tool steel unusual type of eutectic carbides, i.e. M_6C, precipitates (see Figure 2b). For cooling rate of 0.25 K/s and applying of inappropriate, i.e. too high soaking temperature (1 180 °C), a microstructure with coarse grains and coarse eutectic carbides (Figure 2c) in final rolled piece was obtained. Further, it was found out that in the case of too high soaking temperature at upper limit of temperature working range, due to coarsening of carbides, the hot workability was decreased. Namely, the number of small carbides decreases and the size of big carbides increases although their fraction changed according to phase equilibrium (diagram). On the contrary in the case of an appropriate soaking temperature (1 150 °C) the initial as-cast microstructure can be transformed into a fine grained microstructure with fine and equally (regularly) distributed eutectic carbides (Figure 2d); the number of large carbides is reduced which results in increased hot workability at upper and lower limits of temperature working range. Thus, the coarser carbides and/or carbide clusters, that have been formed during soaking, represent the spots for initiation of micro-cracks during initial stage of hot deformation as well as during final stage of hot deformation; thus by applying of appropriate soaking temperature the process of coars-

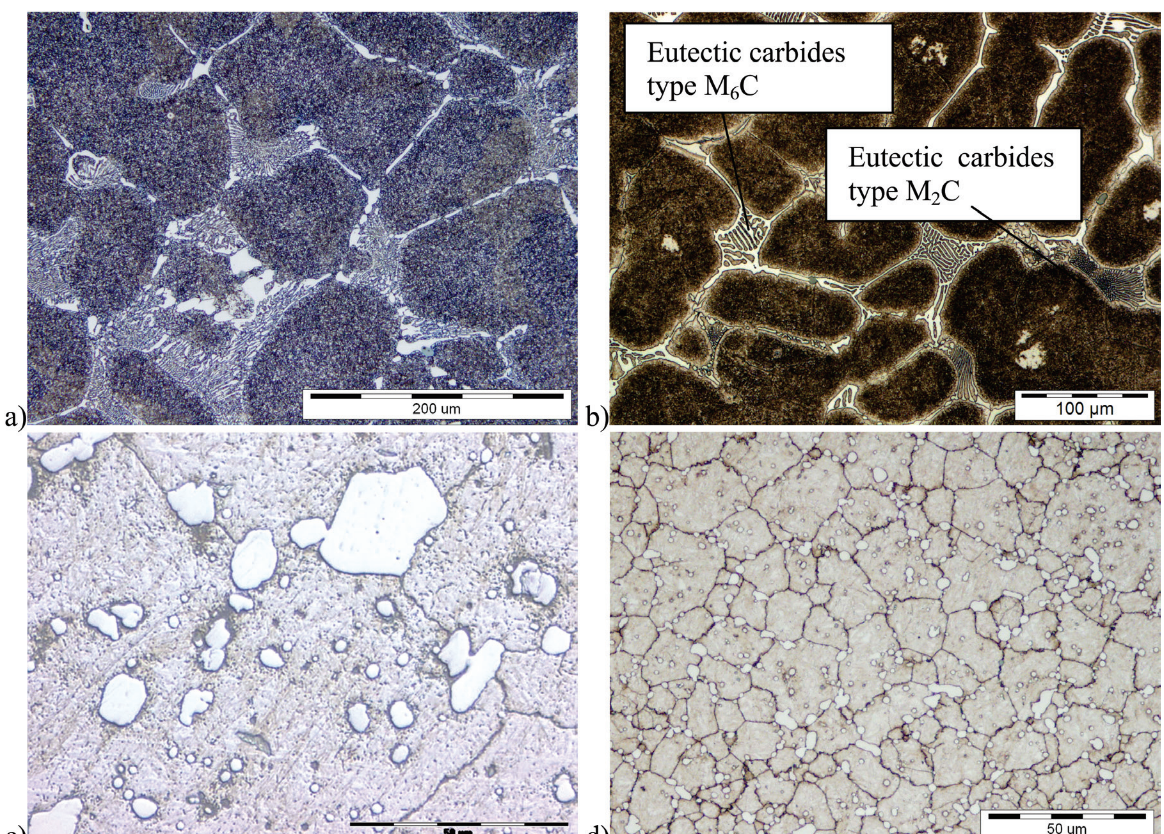

Figure 2: *Microstructure for M42 tool steel obtained at solidification rate of* 0.25 K/s *(a) and at solidification rate of* 0.16 K/s *(b), obtained microstructure after hot rolling applying of inappropriate (too high) soaking temperature of* 1 180 °C *for (c) and microstructure obtained in rolled piece at appropriate soaking temperature* 1 150 °C *(d).*

ening of carbides will be avoided which leads to extended temperature range of safe hot working. Similar results regarding the soaking conditions were obtained also for D2 and W.Nr.1.2690 tool steels.

Furthermore, these results show that the process of dissolution of fine carbides and coagulation as well as growth of coarser carbides during soaking before the hot deformation is irreversible. In the case of applying of too high soaking temperature with subsequent hot rolling the coarser carbides that form during soaking cannot be broken down and consequently coarser eutectic carbides are present in the final microstructure which also influences the mechanical properties of the final product.

Thus applying the soaking at too high temperature leads to decreased deformability at upper as well as at lower limits of temperature working range; this plays important role especially in hot deformation in several heats (reheating – deformation cycles) in industrial conditions.

Too slow cooling rates (microstructure on Figure 2b), as in the case of casting at too-high temperature (for 1.2690 tool steel (Figure 1)) result in occurrence of a new type of eutectic carbides that further leads to decreased hot deformability as it has been already presented in the case of casting at too high temperature. Thus too high casting temperature and too slow cooling rates of ledeburitic tool steels cannot be considered as mutual independent but as mutual dependent influential parameters.

Influence of soaking temperature on hot workability for microstructures in continuously casted billet

Influence of initial microstructure on selection of appropriate soaking temperature (M42 tool steel) will be illustrated on continuously cast billet square of 130 mm. Figure 3a shows as-cast microstructure 25 mm under the surface of the billet. In accordance with the described procedure in section 2 or in[1] temperature of

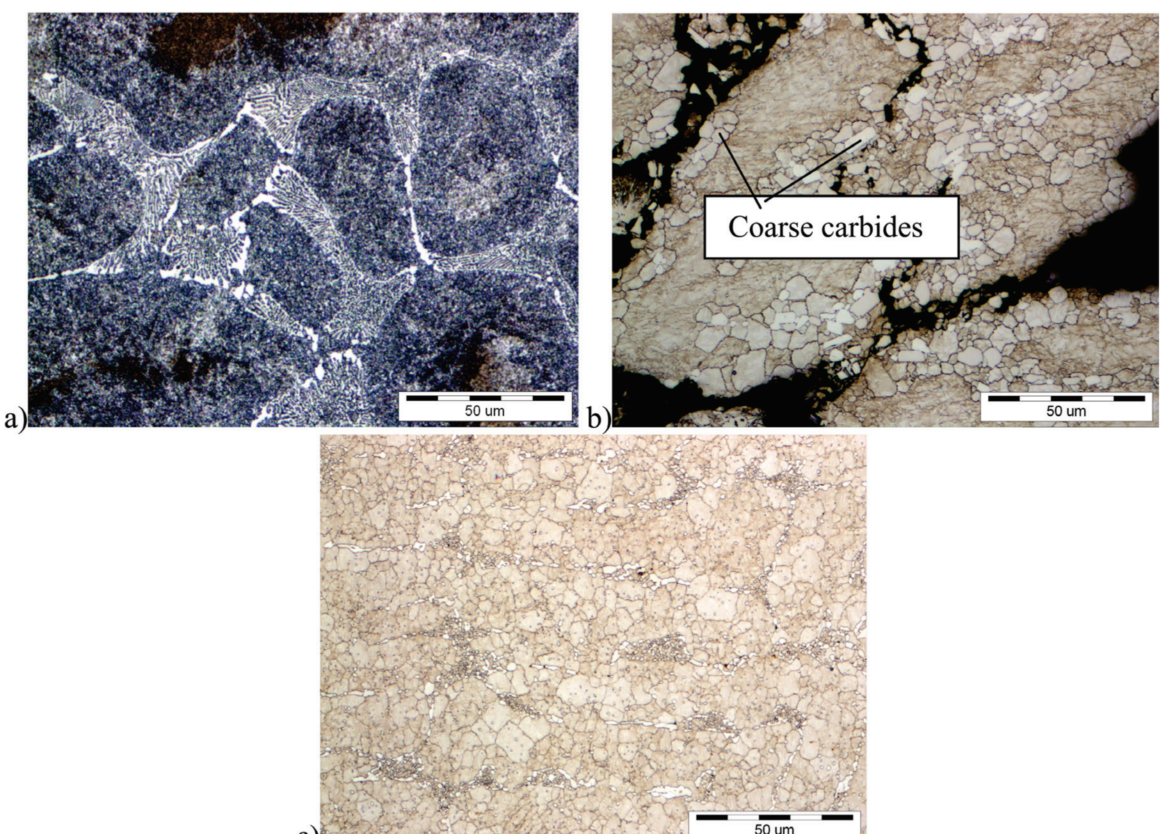

Figure 3: *Influence of soaking temperature on coarsening of carbides and on hot deformability for continuously cast M42 tool steel on upper limit of temperature range: initial as-cast microstructure (a); soaking and deformation temperature* 1 170 °C *(b); soaking and deformation at temperature of* 1 140 °C *(c).*

1 140 °C was determined as appropriate soaking temperature. Figures 3b-c shows the results of the influence of soaking on coarsening of carbides so at appropriate (1 140 °C) as well as at too high (1 170 °C) temperature and their influence on hot deformability. During soaking at 1 170 °C coarse carbides were formed that lowers hot deformability; this results in cracking along previous dendrite grain boundaries, where these carbides are concentrated (Figure 3b). At soaking temperature of 1 140 °C the coagulation and coarsening of carbides was not remarkable and the deformed sample did not crack (Figures 3c). It means that also in the case of soaking at too high temperature and subsequent hot deformation on lower temperature (a.m. 1 140 °C) the material will exhibit lower hot deformability due to presence of oversized carbides in matrix. Applying the soaking temperature of 1 150 °C, which was appropriate for the microstructure obtained at 0.25 K/s, for the continuously cast billet in Figure 3a led to decrease in hot deformability. Thus for each initial as-cast microstructure appropriate soaking temperature should be individually selected.

Conclusions

The results of the study of the influences of casting temperature, cooling rate and soaking temperature on the hot workability of ledeburitic tool steels can be summarised as follows:

- Selecting the correct values for casting and cooling rate as well as for soaking temperatures improves the intrinsic hot workability of the investigated ledeburitic tool steels.
- At a too-high casting temperature small unusual and/or small complex carbides additionally precipitate in the matrix during solidification. Cracking during hot deformation then predominately occurs along these carbides.
- A too-low cooling rate also results in precipitation of additional type of carbides, which are usually not formed during solidification at higher cooling rate. Due to their different properties they deteriorate the hot workability and influence the properties of the final products.
- The soaking temperature influences the dissolution, the spheroidisation, the coagulation and the growth of carbides, and the growth of austenitic grains. Selecting the appropriate soaking temperature extends the temperature range of safe hot working, so at its lower as well as at its upper limits. A too-high soaking temperature for a particular soaking time results in coarser carbides which leads to decrease of the hot workability at both limits of the temperature working range.

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