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Influence of forging technology on structure and properties of heat-resisting steels

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Heat-resisting steels are characterised by specific properties, which can substantially complicate technological procedure of their forming. They are distinguished by increased resistance to deformation, narrow interval of forging temperatures, impaired formability, high sensitivity to stresses, particularly to temperature ones.

1. INTRODUCTION

Some steel grades are characterised by their susceptibility to cracking at low finish-forging temperatures, cracking at non-controlled cooling from finish-forging temperatures. They have tendency to segregate phase on boundaries of grains, create coarse grain at high finish-forging temperatures, which can be removed by the subsequent heat treatment only with difficulties. They are distinguished also by high temperature of the beginning of re-crystallisation and low re-crystallisation rate. Forming of heat-resisting steels containing approx. 12% of chromium takes place in a two-phase state austenite – delta ferrite. Forming of steels in a two-phase state austenite – delta ferrite is more difficult since during forming cracks can be formed at the boundary of both phases [1].

Structures of heat-resisting chromium steels containing approx. 12 % of chromium, in dependence on modification of chemical composition and on mass of ingot, can be at forming temperatures either single-phase – austenitic, or two-phase, which means that structure contains apart form austenite also delta ferrite.

Presence of delta ferrite and its quantity is controlled by contents of carbon in steel and by quantity of carbide forming elements. The lower the carbon contents and the higher the contents of carbide forming elements, the higher is the delta ferrite contents in the structure. When the temperatures is higher than 1200 ^{o}C a delta ferrite appears in the structure, and its quantity increases with the increasing temperature. Presence of delta ferrite in non-modified chromium steels is suppressed by smaller addition of nickel. If the carbon content is lower, the delta ferrite appears in the structure already at lower temperatures.

Addition of modifying elements Mo, V, Nb, B increases possibility of occurrence of delta ferrite and there can occur even a case, when the delta ferrite occurs in the structure already at temperatures of approx. 20 ^{o}C [2]. According to the equilibrium diagram below the transformation temperature the austenite is transformed to ferrite and carbides. If the cooling is sufficiently quick, the martensite is formed in heat-resisting steels containing approx. 12% of chromium.

We have carried out experiments on two steels, the chemical composition of which is given in the Table 1.

Table 1. Chemical composition of investigated steels

Steel grade	Contents of elements[%]											
	C	Mn	Si	P	S	Ni	Cr	Mo	W	V	Nb	B
X20CrMoV 12-1	0,19	0,8	0,31	0,025	0,017	0,60	12,24	0,80	-	0,33	-	-
Cr12MoWNbV(B)	0,22	0,68	0,37	0,022	0,012	0,52	11,45	0,60	0,59	0,27	0,22	0,003

2. STRUCTURAL CHANGES IN THE ZONE OF FORGING TEMPERATURES

2.1. Classical steels

Micro-structure of classical heat-resisting steel without alloying elements niobium, tungsten and boron is austenitic up to the temperature of 1150 ^{o}C. At the temperature of 1200 ^{o}C a small quantity of the delta ferrite begins to be formed. After heating to 1250 ^{o}C to 1300 ^{o}C there is being formed apart from the delta ferrite along boundaries of austenitic grains dark mesh of carbides, which manifests enrichment of grain boundaries by alloying elements (fig.1).

Non-homogeneity in distribution of alloying elements caused by heating to a high temperature was demonstrated also on other samples, which were repeatedly austenitised at lower temperatures. With increasing temperature of austenitisation there occurs gradually a back diffusion, and at the temperature of 1150 ^{o}C the mesh at the grain boundaries is removed (fig. 2).

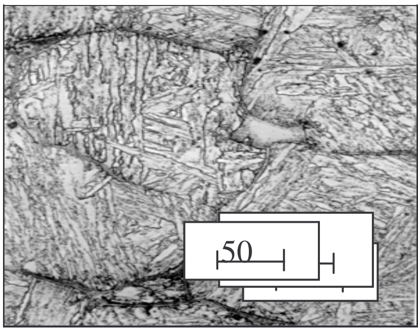

Fig.1 Structure of steel X20CrMoV 12-1

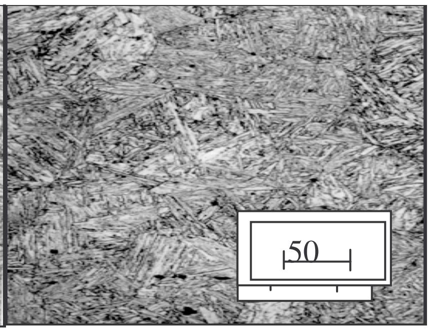

Fig.2 Structure of steel X20CrMoV 12-1

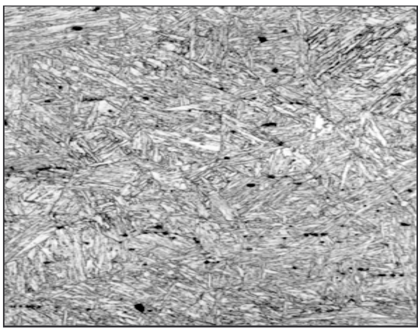

Fig .3 Structure of steel X20CrMoV(B) 12-1

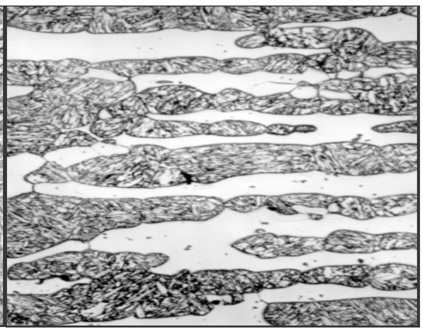

Fig. 4 Structure of steel (B) 12-1 with lower carbon contents

In the heat-resisting steel x20crmo v12-1, modified by addition of b in the whole interval of forming temperatures from 900 to 1300 ^{o}C the delta ferrite has not been identified (fig. 3), probably due to influence of carbon and nickel. In steels with the similar chemical composition, but with lower carbon contents than in the previous case, reduction of the carbon contents has strong impact on the increased occurrence of the delta ferrite, the quantity of which in the structure varies at the temperature of 1000 ^{o}C around 50 %(fig. 4).

Contents of delta ferrite in this steel increases with the increasing upper forging temperature. Due to the fact that forging of free forgings is made with several re-heatings, it ispossible, particularly at the stage of finish forging, that some part

Of the forged piece will not be forged at all after the last re-heating and size of grain and contents of ferrite in this part will be substantially bigger than in remaining parts. In the steels with high contents of delta ferrite the size of grain and the contents of delta ferrite increases at high temperatures of re-heating [3].

2.2. Heat-resisting steels modified by niobium and boron

Steels with niobium and low contents of boron (0,003 %) contain at the temperature of 1050°C approx. 5% of ferrite. We have investigated informatorily in steels with higher contents of boron (0,025 %) their formability and verified the influence of high temperature of re-heating on final structure of the forging.

2.3. Grain size

Optimal size of grain after thermal treatment is the decisive factor for obtaining of satisfactory mechanical properties of forged pieces. Size of grain is important also during forming of steel, since too coarse grain impairs formability of steel. One of the reasons why high forging temperatures are not used, is the fear of forming of coarse grain, which increases with the increasing re-heating temperature. Although coarse grain, which was formed during re-heating to forging temperatures, gets finer during forging, in large forged pieces, which are forged with use of several re-heatings, there can occur places, which are not re-forged after the last re-heating and the grain remains to be coarse. In spite of the fact that in heat-resisting steels containing approx. 12 % of chromium there occurs a transformation of austenite to martensite, the delta ferrite, which occurs in the structure during forging, does not change [3].

2.4. Distribution of delta ferrite in structure

It is obvious from the metallographic photos given above that the delta ferrite is distributed in the steel structure after forging always in rows. The photos were taken from samples made of forged bars and direction of the ferrite rows is parallel to the axis of the forged bar, i.e. That deposition of ferrite is oriented by forging in direction of elongation of the bar.

3. FORMABILITY OF HEAT-RESISTING STEELS

Due to the fact that heat-resisting modified steels with 12 % of chromium contain in structure apart from austenite also delta ferrite, this is forming of two-phase steels. Many studies were devoted to the forming of two-phase steels, in which generally presence of the second phase is regarded as strongly unfavourable.

According to these studies the steels in a two-phase state austenite-delta ferrite are formable with difficulties, since cracks occur during forming at the interface between the two phases. Literature very often points out the unfavourable influence of delta ferrite in austenitic steels of CrNi type 18/8, which is formed in these steels at higher temperatures of re-heating or at inappropriate proportion of chromium and nickel, or possibly molybdenum [4]. Ferrite with its body centred lattice has due to larger number of slip systems better plastic properties than face centred lattice of austenite. Overall plasticity decreases if smaller quantity of gamma phase occurs in the ferritic structure [5].

Verification of formability has been made by laboratory tests, which on one hand cannot fully characterise industrial operation conditions, namely problems related to non-homogeneity of large ingots, but evaluation of which on the other hand can be made more objectively. Formability was verified on forged bars with use of hot tensile test, which was completed with dupsetting tests. Assessment of formability was made on the basis of final values of strength, contraction, as well as by evaluation of appearance of the fracture surface and upsetting test after deformation.

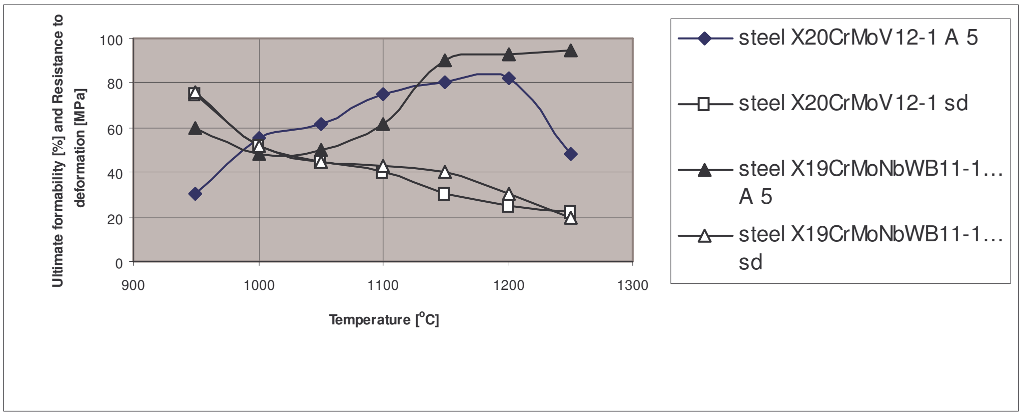

Fig. 7 Formability and resistance to deformation of the steel grade X20CrMoV 12-1 and steel grade X19CrMoNbWB11-1

Table 2. Final mechanical properties of forged pieces after thermal treatment

Steel	Mechanical properties of forged pieces			
	Rm [MPa]	Rp0,2 [MPa]	A5 [%]	KC [J]
X20CrMoV 12-1	700	500	14	40
Cr12MoWNbV(B)	750	550	14	40

4. CONCLUSION

Verification of formability of the steels mentioned above was made due to the fact that these steels are in the interval of forming temperatures two-phase steels. Hot formability was verified with use of hot tensile and upsetting tests. The results of tests have proved unequivocally that formability of these heat-resisting steels modified by Mo, W, V is in comparison with classical heat-resisting steels impaired. Deteriorated formability can be explained by the presence of carbide-forming elements in the steel. It is evident from the experiments, that deterioration of formability is not directly linked to the presence of the delta ferrite in the structure. Optimal forming temperature of steels varies in the interval of temperatures between 1000 to 1200 ^{o}C. Due to lower re-crystallisation rate and possibility of segregation of carbides in deformed grains of steel at the low forming temperature it is appropriate to make big deformations at higher temperature, and finish-forming temperature may not fall under the temperature of 1000 ^{o}C. Influence of addition of niobium and boron (only up to 0,005 %) does not impair significantly the formability. Due to unfavourable properties of boron at high temperatures of re-heating it is necessary to limit the upper forming temperature to 1200 ^{o}C. Higher contents of boron ion steel (around 0,025 %) distinctively deteriorates formability in the whole interval of forming temperatures. Steels containing 0,033 % of boron have substantially impaired formability and possibility of their processing with use of classical forging technology is thus limited.

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