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Austenite stability in the high strength metastable stainless steels

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ABSTRACT

Purpose: The aim of the present paper was to study the peculiarities of the austenite to martensite phase transformation (A-M), which is an essential step in the production technology of the high strength metastable stainless steels.
Design/methodology/approach: The desired control over A-M transformation have been achieved by proper design of the steel chemistry, cold working and heat treatment.
Findings: For a range of steel compositions, it was shown that severe cold working leads to fully martensitic structures. Alternatively, the deep refrigeration treatment or heating at about 750°C, are also effective in that respect. Subsequent ageing treatment of the deformed martensite, or martensite obtained by subzero treatment, develops interesting set of the mechanical properties.
Research limitations/implications: To fully evaluate the properties of the steels further research is needed, particularly involved with the cold drawing and ageing response.
Practical implications: The new metastable stainless steels could achieve properties making them competitive to some high strength steels and alloys - those with not so good combination of formability, strength and corrosion resistance
Originality/value: Revealed transformation behavior of the complex alloyed austenites makes an essential step in development of the high strength metastable stainless steels.

Keywords: Heat treatment; Metastable austenite; Martensitic stainless steels; Cold working

1. Introduction

The metastable stainless steels, also known as the controlled-transformation stainless steels, try to combine the best properties of the austenitic and martensitic steels [1÷5]. They are used primarily in the form of sheets, strips and wires. The fabrication in the sheet form is made in the austenitic state. After annealing the soft austenitic structure is obtained, which transforms to martensite during subsequent operations such as cold working or refrigeration. The last operation is ageing, which provides the steel with additional strength. Steel toughness is strongly dependent upon particular grade and treatment. These steels are not so readily drawn or formed as stable austenitic stainless steels, but they may have good combination of the formability, strength, ductility and corrosion resistance, which make them competitive to other high strength steels and alloys. For example, the high strength quenched and tempered steels often require surface protection involving polluting agents, and for the environmental reasons the high strength stainless steels are gaining renewed interest. When making parts of the high strength stainless steels, stability of the austenite is one of the major concerns. The problem of the retained austenite stability has recently been studied also in the TRIP-aided low alloy steels [6, 7].

For several steels of widely varied chemical compositions, the austenite stability during cold rolling and refrigeration has been studied, to evaluate the degree of control that could be achieved over microstructure and resultant mechanical properties.

Table 1.
Chemical composition of the stainless steels, 25 kg laboratory melts, [wt.%]

Steel	C	N	Cr	Ni	Mo	Mn	Si	Al	Cu
1H14ANG2SCu(A)	0.10	0.10	14.0	1.5	0.50	2.0	1.5	-	1.5
0H15N6SCuJ(B)	0.07	-	15.0	6.0	-	1.0	1.5	1.20	1.5
1H15N4AM3(N)	0.15	0.10	14.57	5.3	2.32	1.09	0.63	0.12	-
0H15N7M2J(J)	0.05	0.02	15.53	7.03	2.3	0.42	0.28	1.08	-
OH12N8M2J(H)	0.02	0.01	11.67	7.9	2.13	0.20	0.10	0.96	-

2. Experimental

To study the microstructure of the steels, routine metallographic procedures of optical microscopy and transmission electron microscopy were used. To measure austenite content in the cold worked steels, the special X-ray diffraction procedure was used, in which many peaks intensity from alpha and gamma phases has been taken into calculation, to compensate for strong preferred orientation of the grains. The subzero transformation of the austenite to martensite has been studied by the dilatation changes using optical dilatometer equipped with the refrigeration chamber.

The chemical compositions of the 25 kg laboratory melted steels are given in Table 1. First three steels: 1H14ANG2SCu (steel A), 0H15N6SCuJ (steel B) and 1H15N4AM3 (steel N), have high interstitials content and high level of silicon and manganese. The (A) and (B) steels have particularly lean specification in terms of expensive elements, such as nickel and molybdenum. The higher nickel is present in the last two steels, but silicon, manganese and interstitials levels are much lower, compared to other alloys. Each steel contains the elements important for the secondary hardening (Al, Cu, Mo, Ni).

3. Results and discussion

Depending on a specific composition, Fe-Cr-Ni-X alloys may have austenitic, martensitic, ferritic or mixed microstructures. The steels microstructures are conveniently presented with the use of Schaeffler diagram, Fig. 1. Compositions of the metastable steels studied in the present work were so balanced that they all fell in the "M-A" region, between the fully austenitic and martensitic fields. The diagram also indicates that some small amount of the delta ferrite should be expected in the steels studied. The Schaeffler diagram serves essentially to predict weld microstructure, and may not be necessarily accurate for microstructures formed by other means.

Fig. 2 shows predominantly austenitic structure with some amount of martensite in the 1H15N4AM3(N) steel after solution annealing at 1050°C. Another example of microstructure in annealed state, where the delta ferrite was revealed in the 1H14ANG2SCu(A) steel is shown in Fig. 3(a).

For the metastable stainless steels there are three basic ways to transform the austenite into martensite:

- refrigeration well below room temperature,
- severe cold working,
- heating at about 750°C.

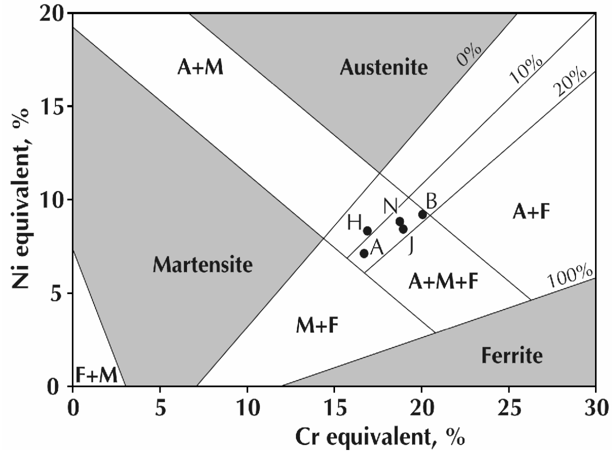

Fig. 1. Location of the metastable stainless steels on the Schaeffler diagram

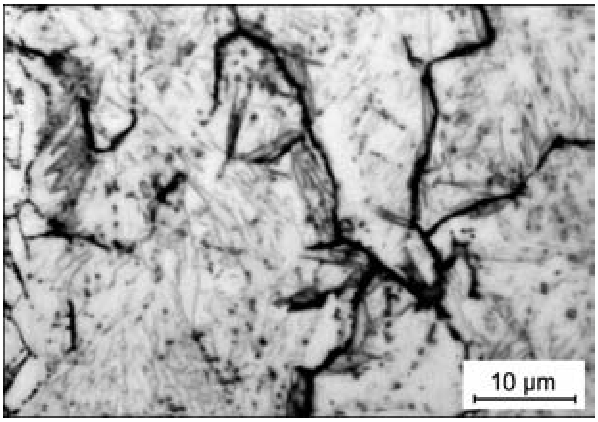

Fig. 2. Austenitic structure with some amount of martensite in the 1H15N4AM3(N) steel after solution annealing at 1050°C (the optical micrograph)

The heating at 750°C causes precipitation of the $M_{23}C_6$ carbide, producing austenitic matrix depleted of the chromium and carbon, what effectively rises the Ms temperature. Microstructures produced in that way have poor properties, both in terms of strength and toughnesss [8, 9]. This heat treatment is of limited value and was not considered any further.

The refrigeration heat treatment is often applied to heat treatment of the tool and medium carbon quenched and tempered steels to eliminate the retained austenite [10÷13].

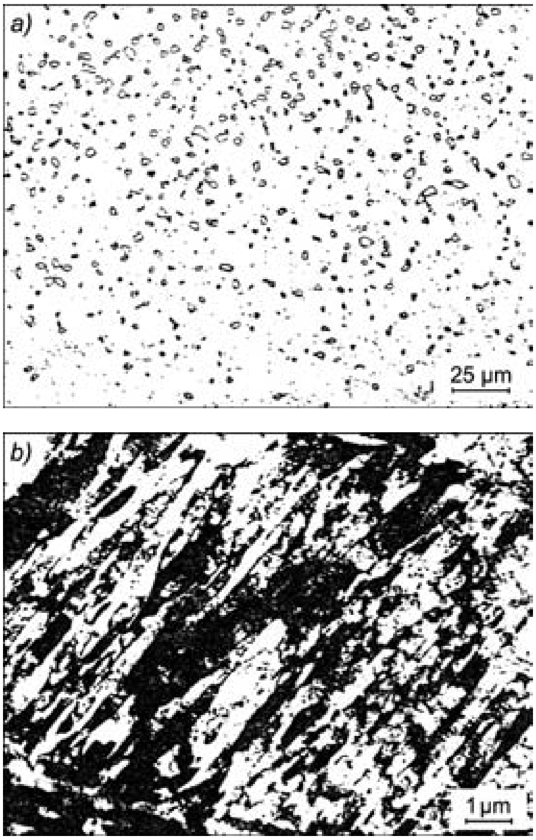

Fig. 3. Microstructures of the 1H14ANG2SCu(A) steel showing: a) δ-ferrite (the optical micrograph); b) martensite formed by cold rolling with deformation of 60% (the transmission electron micrograph)

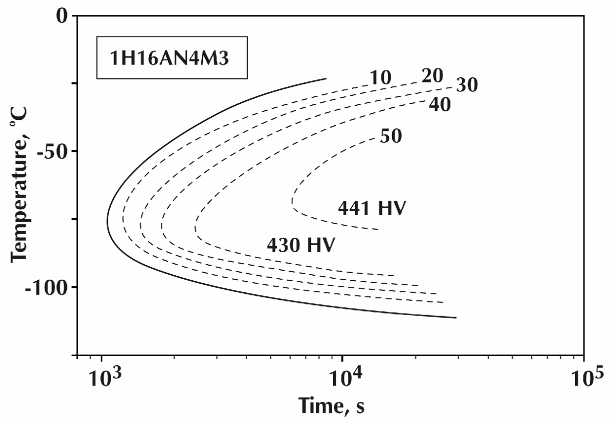

Fig. 4. Isothermal kinetics of the austenite to martensite transformation in the 1H16AN4M3 steel at subzero temperatures

The isothermal transformation of austenite to martensite at the subzero temperatures in the 1H16AN5M3 steel is shown in Fig. 4. The kinetics of transformation has a C-shaped curve, and proceed with greatest rate at the temperatures close to -80°C. The refrigeration treatment should be made within short time after solution annealing, otherwise the stabilization may occur.

Example of microstructure obtained in the (A) steel after cold rolling with deformation of 60%, is shown in Fig. 3(b). Apart from martensite, there are highly deformed ferrite grains but they were not clearly seen on the transmission electron micrographs. The effect of cold deformation by rolling on the austenite stability has been studied for the 1H14ANG2SCu(A), 0H15N6SCuJ(B) and 0H15N7M2J(J) steels, Fig. 5. The greatest strain hardening rate is observed in the 1H14ANG2SCu(A) steel which have highest interstitials content.

This steel developed most of its maximum hardness (“saturation hardness”) at cold reductions up to 30%. For the (B) and (J) steels, having lower interstitials content (<0.10%), the hardness increases more gradually over the range of cold reductions studied.

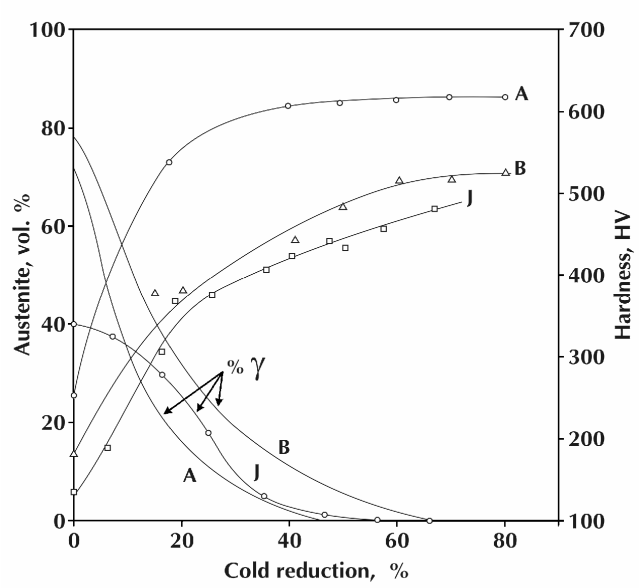

Fig. 5. The effect of cold deformation by rolling on the austenite stability and hardness of the metastable steels (A, B and J)

Table 2 shows results of the tensile test of solution annealed steels. The 1H15N4AM3(N) and 0H15N7M2J(J) metastable steels have low yield stress and develop very high strengths after straining. The observed strength gap between yield stress and ultimate tensile strength could be as high as 930 MPa. In the tensile test of the (N) and (J) steels, the high strain hardening rate is accompanied with large relative elongations - both at fracture, and as measured at the point of maximum force, Ag_t (the uniform elongation). Such large elongations were not observed in the 0H12N8M2J(H) martensitic steel of similar resultant strength. Apparently at tensile straining of the steels with higher interstitials content, the austenite transforms to martensite giving the effect of the transformation induced plasticity. It is interesting to note that the progress of the M-A transformation during mechanical loading could be studied by the neutron diffraction [14, 15].

Table 2.
Mechanical properties of the metastable stainless steels in the annealed condition

Steel	YS MPa	UTS MPa	R.A. %	Elong. %	Ag_t* %
1H15N4AM3(N)	332	1267	32	22.4	17.5
0H15N7M2J(J)	324	981	-	15	-
OH12N8M2J(H)	817	1024	56	5	2.4

* the elongation at maximum force

Preliminary testing of the final mechanical properties of (A) and (B) steels, after 60% cold working and ageing, showed that at 0.01% proof stress of 1650 and 1350 MPa, respectively, they have adequate fatigue strength for the spring application. After final ageing the 0H12N8M2J(H) steel had yield strength of 1400 MPa and fracture toughness over 50 MPa·$m^{1/2}$, what is satisfactory for many structural applications.

4. Conclusions

For a range of the complex alloyed stainless steels with the metastable austenite, transformation and mechanical property data have been presented. Beginning with initially predominant austenitic structure, fully martensitic structure could be obtained by cold rolling with reduction of over 50%. The refrigeration treatment at about -80°C, or heating at temperatures around 750°C were also effective in destabilizing of the austenite. The high strain hardening rate of the metastable steels in annealed state was accompanied with the large uniform elongations, apparently as the result of austenite to martensite transformation.

Preliminary evaluation of the final mechanical properties obtained after cold working and ageing indicate that the lean alloyed 1H14ANG2SCu(A) and 0H15N6SCuJ(B) steels may find applications in the form of small gage strips and wires. The richer alloyed OH12N8M2J(H) steel with low interstitials content, have properties suitable for high strength structural applications. Due to a good combination of strength, formability and corrosion resistance, the metastable stainless steels could be competitive to many high strength steels and alloys.

Acknowledgements

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