The effect of intense external influences on the structure and properties of alloys

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For the production of special high-wire thin and very thin sections austenitic steel has been widely adopted. Developed carbon-free highly alloyed Fe-Cr-Ni based steel in the quenched condition has a high plasticity, manufacturability and low strength. High adaptability of these steels allowed conducting extensive plastic deformation as shear under pressure and drawing. Prerequisite for a high plasticity and adaptability of the developed steels are: their doping with low carbon, 0.03% C, as well as cobalt and nickel content, which increase the plasticity of steels. Secondly, the presence of strain-metastable austenite, which during severe plastic deformation is almost completely transformed into deformation martensite and the related TRIP-effect. Especially important is the fact that thanks to high steels manufacturability, the effect of severe plastic deformation leads to the formation of submicro- and nanocrystalline structure (mainly with high-angle misorientations at grain boundaries with high strength) in long workpieces. The aging of the deformed steels causes an additional increase of mechanical properties, which is associated with the occurrence of a supersaturated BCC solid solution (strain martensite). The resulting allocation of intermetallic phase NiAl is nanocrystalline, which is especially important in obtaining the finest wire diameters. It should be noted that ageing can be performed on finished products.

Keywords:
plasticity, manufacturability, strain-metastable austenite, severe plastic deformation, TRIP-effect

INTRODUCTION

Obtaining of bulk nanostructured metals and alloys by SPD (severe plastic deformation) is an important and rapidly developing area of modern materials science, which aims at the creation of materials with high physical and mechanical properties. Submicrocrystalline state making can use various types of thermoplastic processing, including SPD by shear under high pressure (IAP), by equal-channel angular pressing (ECAP), by rolling with ultra-high degrees of plastic deformation, as well as drawing. In connection with the modern tendency to miniaturize products, there is a need to create new tools, as the ones use in microsurgery, as well as elastic elements, and springs for precision machinery and instrument, made of thin or fine wire. The most important in their development is the selection of materials that would significantly improve quality, reliability, durability and functional properties.

Metastable austenitic steels are widely used in industry for the production of special high-wire thin and delicate sections, designed for the manufacture of elastic elements. However, not all of these are characterised by good processability and ductility. Thus, the metastable austenitic steel 12X18H10T, one of the major industrial steel for the production of stainless cold-drawn wire, has serious flaws, poor mechanical properties (even in the deformed state).

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Given the above, practically carbon-free (P <0.03%), high-strength corrosion-resistant austenitic steel in the Fe-Cr-Ni-based, alloyed additionally Co, Mo, Ti and Al. It was developed to manufacture high strength-wire thin and very thin sections. In this paper, the influence IAP on structure, phase composition and properties of investigated steel had been discussed.

RESULTS AND DISCUSSION

It is known that the formation of high-strength state in austenitic steels with a metastable structure ensures the implementation of thermoplastic processing, including quenching by saturated γ-solid solution, followed by cold drawing and the final post deformation aging. Preliminary studies on these steels have shown that the optimum heating temperature for hardening, in terms of the formation of a better set of physical and mechanical properties for subsequent cold plastic deformation is a temperature 1000-1050 °C in water. Experimentally it was established that cobalt in the studied steels in the amount of ~4.5-5.0% leads to complete suppression of the δ-ferrite formation. After softening heat treatment the mechanical properties of steel are: σ_b = 550 MPa, $\sigma_{0,2}$ = 245 MPa, ψ = 80%, δ = 60%, hardness 140 HV, microhardness 200 HV. Metallographic studies showed that after quenching a steel has a typical polyhedral structure with a large number of annealing twins, which are characteristic of austenite with a low energy stacking faults. Carbon-free Fe-Cr-Ni-austenite has a high reserve of plasticity due to the high density of highly mobile dislocations and the almost complete absence of interstitial atoms. This allows for an intense cold plastic deformation by any of the above methods.

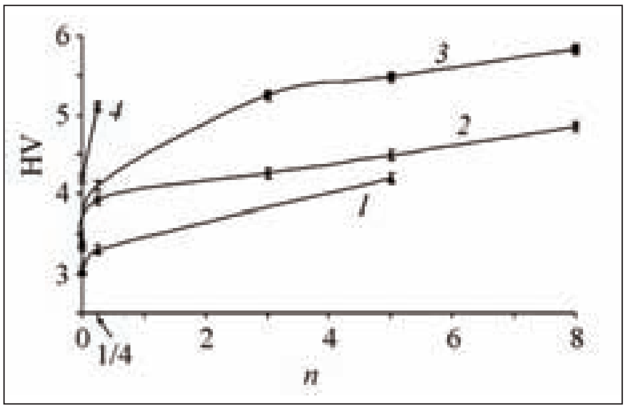

Fig. 1 - Dependence of steel 03X14H11K5M2ЮТ microhardness on the number of turns n and the applied pressure, GPa: 1 – 3,2 – 5,3 – 8,4 – 10.

Dipendenza della microdurezza dell'acciaio 03X14H11K5M2ЮТ dal numero di giri n e dalla pressione applicata, GPa: 1 – 3,2 – 5,3 – 8,4 – 10.

Initially, the potential of the investigated steel to deformation was evaluated. IAP study were carried out on Bridgman anvils compressed at pressures 3, 5, 8 and 10 GPa as a simultaneous shift to ¼, 3, 5 and 8 turns, and without the shift. The effect of IAP on the phase composition, hardness and microstructure had been studied on the obtained samples.

Deformation at a pressure of 3 GPa caused a slight $\alpha \rightarrow \gamma$ transformation but with increasing pressure from 3 to 10 GPa, the amount of deformation martensite increased from 7 to 43%, respectively. It was found that the greater the applied pressure, the higher the hardness of austenitic steel 03X14H11K5M2ЮТ. The greatest increase in the hardness of the steel is achieved by SPD compression under pressure with torsion.

Electronic-microstructural studies showed that at 5 GPa the high elastic stress field in the structure was created, due to the emergence of a high density of dislocations. Increasing the applied pressure to 8 GPa leads to an increase of elastic stresses. The microdiffraction pictures show, that reflections are orientationally dependent, and this allow to draw conclusions about the possible presence of ε- and α-martensite. IAP at 5 GPa with a shift (n = 3, 5 and 8 speed) leads to an increase in martensitic transformation, which in turn promotes the growth of microhardness. Fully BCC phase were detected at 8 GPa and 8 speeds. As a result of this deformation, the martensite plates are broken. The size of martensite crystals ranges from 200 to 50 nm. The circular diffraction patterns indicate the emergence of a nanostructured state. Such a severe plastic deformation leads to a significant increase in microhardness of more than 2.5 times as compared with the original quenched state. Subsequent postdeformation aging leads to a significant increase in the hardness of 160-330 HV (depending on the amount of martensite, formed during IAP deformation). This increase in hardness during aging is associated with the processes of decomposition of the supersaturated BCC solid solution (deformation martensite) with the formation of highly dispersed intermetallic phases (Fe, Ni) Al. Since the main purpose of the study was the obtaining of long products (wire) with the SMC structure by the SPD in an industrial conditions, it was of interest to consider the impact of intense degrees of reduction of cold drawn wire to the structure, phase transitions and complex physical and mechanical properties. It is known that the martensitic $\alpha \rightarrow \gamma$ transformation runs noticeably stronger in tension than in compression. There are two reasons. Firstly, the formation of deformation martensite is accompanied by an increase in volume, and the application of compressive stresses prevents the transformation of $\alpha \rightarrow \gamma$. Second, the process $\alpha \rightarrow \gamma$ transformation affects also the fact that metals with FCC lattice in tension and compression occur in different deformation texture. Tensile shear stresses on {111} planes, which is the movement of dislocations during plastic deformation is higher than in compression, which leads to the formation of more martensite.

Plastic deformation by drawing with high total degree of reduction leads to a significant increase in the strength in 3.5-4.0 times. Gain strength at the same time was $\Delta\sigma_b$ = 1650-1700 MPa (Table 1).

Low carbon content, the presence of strain-metastable austenite and pronounced trip-effect, which occurs in this steel 03X14H11K5M2ЮТ, are among the factors that determine its high manufacturability, which allows the cold plastic deformation with extremely high degrees of compression (e = 2.32, 3.2, 4.3, 5.2, 5.9) and significantly re-

Treatment	σ_b, MPa	$\sigma_{0,2}$, MPa	δ, %	ψ, %	BBC crystal's size
Quenching 1000°C	540	245	63	83	
Q+Deformation e = 0,52	760	660	10	80	25-40 mkm
Q+Deformation e = 1,15	1050	940	8	73	400-800 nm
Q+Deformation e = 1,60	1220	1080	6	70	300-500 nm
Q+Deformation e = 2,17	1480	1200	4	70	20-100-200 nm
Q+Deformation e = 2,32 (from Ø 14,3 to 2,77 mm)	1500	1300	3	70	20-100 nm
Q+Deformation e = 4,3 (from Ø 7,0 to 0,8 mm)	2100-2160	1190-1420	3-2		20-100 nm
Q+Deformation e = 5,2 (from Ø 7,0 to 0,5 mm)	2000-2150	1000-1400	2		
Q+Deformation e = 5,9 (from Ø 3,0 to 0,15 mm)	2200		Strength of the gap junction ≈ 50 %		

TAB. 1
The mechanical properties were investigated at drawing.

Le caratteristiche meccaniche sono state determinate in sede di trafilatura.

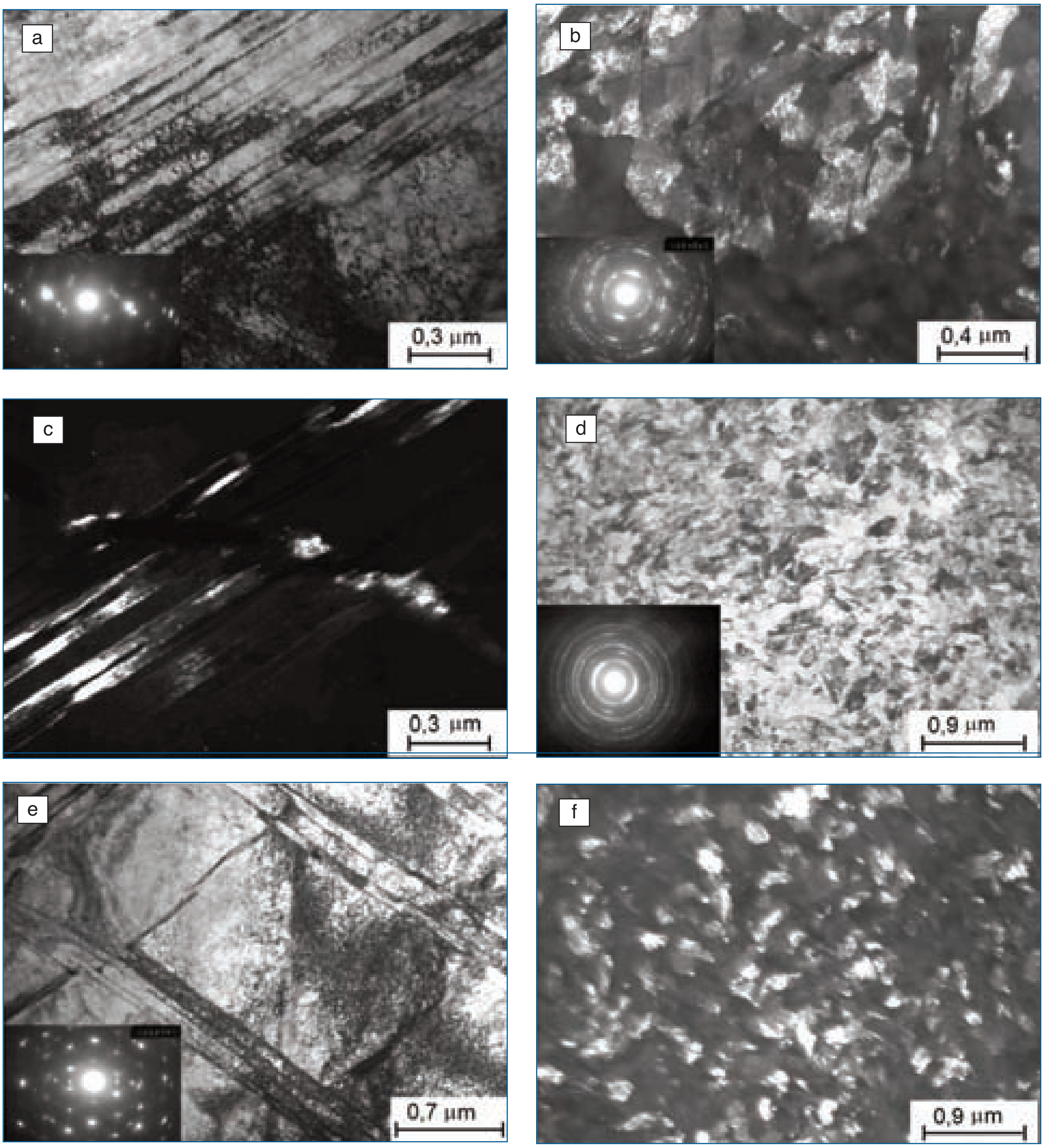

Fig. 2 - Structure of a steel 03 14 11 5 2: a – after deformation e = 0.39 (30 %); b – dark-field image in a reflex ε-phases 12,4$_{\varepsilon}$ after deformation e = 0.39 (30 %); c – after deformation e = 0.52 (41 %); d – dark-field image in a reflex γ-phases (111)$_{\gamma}$ after deformation e = 2.17 (88 %); e – after deformation e = 2.32 (≈ 94 %); f – dark-field image in a reflex α-phases (011)$_{\alpha}$ after deformation e = 2.32 (≈ 94 %).

Struttura di un acciaio 03 14 11 5 2: a – dopo deformazione e = 0.39 (30 %); b – immagine in campo scuro in una fase ε riflessa 12,4$_{\varepsilon}$ dopo deformazione e = 0.39 (30 %); c – dopo deformazione e = 0.52 (41 %); d – immagine in campo scuro in una fase γ riflessa (111)$_{\gamma}$ dopo deformazione e = 2.17 (88 %); e – dopo deformazione e = 2.32 (≈ 94 %); f – immagine in campo scuro in una fase α riflessa (011)$_{\alpha}$ dopo deformazione e = 2.32 (≈ 94 %).

duce the number of intermediate softening treatments in the production of goods or intermediate inputs. Sharp loss of ductility was not observed up to e = 3.2 in the studied steels. It should be noted that in the case of small metal products using of high alloying steel with expensive metals in chemical composition does not lead to an increase in product costs. But reducing of the number of intermediate softening treatment significantly reduces the cost of the product or intermediate product.

A study of the substructure of the metastable austenitic steel after cold plastic deformation made it possible to establish the following: at low degrees of compression ≈ 30% (e = 0,39) on the background of uniformly distributed dislocations appear numerous stacking faults and twins (Fig. 2, a, b, c), which are located firstly on the single shift system {111} <112>, and then, with increasing degree of deformation - on two or more systems.

Strain microtwins become quite extensive, acquiring a curved shape due to plastic deformation of the surrounding matrix. It is also possible that microtwins in the structure of deformed steel is present together with γ-phase and ε-martensite. The presence of ε-martensite in the investigated metastable steel 03Kh14N11K5M2YuT has been observed even at 30-40% strain. This existence of which is shown by the figures of microdiffraction, and darkfield images in the ε-phase reflex (Fig. 2b). This is possible, apparently, due to the nature of the cobalt alloying. Formation of ε -martensite was observed only at low degrees of strain (10-15%) in industrial corrosion-resistant steel 12Kh18N10T, as well as in cobalt-free steels such a system of doping (03Kh14N11M2YuT). The presence of ε-martensite was observed till 40% strain in the structure of investigated steel. That indicates that cobalt inhibits the formation of α-martensite in the initial stages of deformation and at the same time enhances the formation of ε-martensite.α-martensite appears in the structure with increasing degree of total reduction to 69% (e = 1.15) and higher, the number of which increases with increasing degree of cold plastic deformation. Deformation martensite is found only in areas with high density of stacking faults.

The appearance of small reflections in the form of the diffraction rings had been observed on the microdiffraction patterns due to formation of SMC structure with reflexes as bcc and fcc phase (Fig. 2d), with the total strain degree 88% (e = 2.17). The size of the martensite phase 20-100 nm (Fig. 2e, f) under strain ≈ 94% (e = 2.32).

Thus, the investigated metastable austenitic steel 03Х14Н11К5М2ЮТ during cold plastic deformation undergoes α→ε→γ transformation. The intensity of martensite formation in the steel in the initial stages of deformation is much smaller than in cobalt-free steel on Fe-Cr-Ni base. Application of SPD eliminates the difference in the content of α-martensite in steels of different doping, which suggests that the doping of cobalt increases the flexibility and adaptability of the investigated steel.

Postdeformation heating leads to an additional increase in strength and rigidity characteristics. The maximum increase of the strength properties was achieved in the temperature range 480-500 °C. Increase in strength (as in the case of IAP) is due to ageing processes that occur in the BCC phase (deformation martensite) with the release of intermetallic phases such as (Fe,Ni)Al. (Fe,Ni)Al is proportional to the fraction of the formed deformation martensite and $\Delta\sigma_B$ = 500 МПa.

The ageing can be carried out on the finished products, which greatly simplifies the technology.

CONCLUSIONS

1. Using the method of compression IAP with shift pressure allowed us to estimate the potential of the steel.
2. The presence of γ→α transformation and the related trip-effect is one of the determinants of high manufacturability and flexibility, which allows the intense cold plastic deformation and the obtaining of a nanocrystalline state structure.
3. Ageing with the release of the intermetallic compound type (Fe,Ni)Al in the BCC phase provides an additional hardening of the investigated steels.

Effetto di fattori esterni intensivi su struttura e caratteristiche delle leghe

Parole chiave: acciaio inossidabile, proprietà

Per la produzione di particolari sezioni sottili e molto sottili per cavi vi è stato un largo impiego di acciaio austenitico. Sono stati sviluppati acciai altolegati privi di carbonio, a base di Fe-Cr-Ni, che allo stato temprato presentano un'alta plasticità, lavorabilità e una bassa resistenza meccanica. Le particolari prestazioni di questi acciai consentono di sottoporli a deformazioni plastiche severe, come taglio sotto pressione e trafilatura. I prerequisiti per ottenere un' elevata plasticità e deformabilità degli acciai sviluppati sono: la composizione con basso tenore di carbonio - 0,03% C – e con cobalto e nichel, che aumentano la plasticità degli acciai. In secondo luogo, la presenza di austenite metastabile indotta da deformazione, che durante una severa deformazione plastica viene quasi completamente trasformata in martensite da deformazione, con il relativo effetto TRIP. Particolarmente importante è il fatto che grazie all'elevata lavorabilità degli acciai, nei pezzi lunghi l'effetto di severa deformazione plastica porta alla formazione di strutture submicro- e nanocristalline (principalmente con disorientazione ad alto angolo per il bordo dei grani con alta resistenza). L'invecchiamento degli acciai deformati provoca un ulteriore miglioramento delle caratteristiche meccaniche, ed è associato all'insorgenza di una soluzione solida sovrasatura bcc (martensite indotta da deformazione). La risultante morfologia della fase intermetallica NiAl è nanocristallina, e ciò è particolarmente importante per ottenere i diametri di filo più sottoli. Va notato che l'invecchiamento può essere eseguito sui prodotti finiti.