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THE EFFECT OF TITANIUM ON PRIMARY AND SECONDARY CRYSTAL STRUCTURE OF MIDDLE-CARBON STEELS

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Abstract
The effect of titanium on the primary and secondary crystal structure of mid carbon steels is presented. It was established that titanium, at optimal level, improves steel strength, plastic and, especially, toughness properties.

Introduction
Numerous investigations of steel microalloying established that the introduction of a very small amount of Ti refined the primary dendrite structure of steel and did caused that further grain growth has been slow-down.

This presentation deals with the complex effect of titanium and nitrogen added into middle-carbon steel. Microalloying pursues the aim of refining primary and secondary structures steel in ingots with different mass. The middle-carbon steels with carbon content 0.45-0.50 % under study.

The input of titanium nitride particle in kind of special master alloys and combined input of titanium and nitrogen in kind of separate materials were carried out. The microalloying elements in kind of ferrotitanium with Ti content 35%, and nitrogen in compound of nitrated manganese with N content 6-7% were added. Microalloying elements content were verified in boundaries, %: nitrogen – 0.007-0.02, titanium 0.02-0.1. For comparison the steel with same compound without microalloying additions was used.

The investigated microalloyed ingots had 0.002, 0.035, 0.5, 0.75, 4.3 and 8.4 t mass. Commercial ingots 4.3 ton and 8.4 ton were processed on rail profile (R50) and tubular billet (diameter 140 mm), accordingly. In commercial conditions different techniques of addition input in liquid steel was tested (in ladle under stream issuing from steelmaking unit, directly in mould in kind of briquettes).

1. Laboratory experiments procedure and results

Laboratory series of experiments was fulfilled on ingots 0.002, 0.035 and 0.5 ton mass. Two variants of the input methods - titanium nitride particle in kind of special master alloys and common input of ferrotitanium and nitrogen- were carried out. Used special master alloys had uniform distribution of titanium nitride particle with size up 2 to 15 μm.

Metallographic examinations shown that both input methods allow to refine the dendrite structure of microalloyed steels. Macrostructure of microalloyed ingots has sufficient distinguishes from compared . In all experimental ingots the microalloying practically prevents of columnar dendrite zone growth. The fine equiaxed dendrite forms in all volume of ingots (Figure 1). The equiaxed dendrites are much smaller (in 2.5-3.5 fold) that in compared ingots and has almost globular shape.

Researches of microalloying of ingots of 0.75 t mass shown that effect of addition of titanium nitride is less, because part of contenting in masteralloys particles of titanium nitride come to surface slag. This demands to increase quantity of added masteralloys for same effect achievement and reduces microalloying technique efficiency.

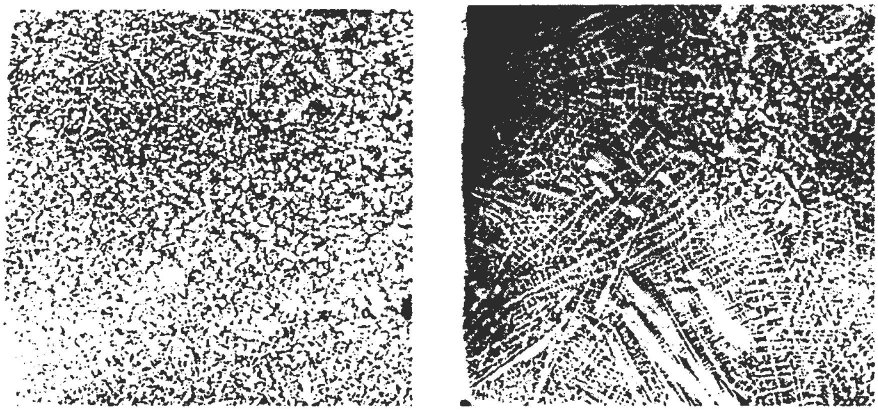
In all investigated ingots the stable modifying effect was obtained. Macro- and microstructure of middle carbon steels sufficiently disperces. The columnar-to-equiaxed transition by titanium microalloying was caused of heterogeneous nucleation on Ti-riched particles (nitrides and carbonitrides).

It has been established that most effective way of titanium microalloying is the methods which foresees the formation of titanium nitride (carbonitride) particles in liquid steel during casting and solidification. Results of laboratory examination were taken into consideration by industrial experiments.

2. Results of metalographic examination of large commercial ingots

The microalloying of commercial ingots 4.3 and 8.4 ton mass was carried out by addition ferrotitanium and nitrated manganese. Most refinement of primary and secondary structure was reached by direct input of additions in mold. Besides "late modifying" techniques provides reducing losses.

Comparison of sulfur prints from longitudinal axial templates of experimental and compared ingots was made.



a b

Figure 1. Fragment of macrostructures of middle carbon steel ingots (0.002 t) with addition 0.04 %Ti) (a) and without microalloying (b) (magnification 6x).

It has been shown that microalloying reduced the axial and inverse segregation - the under shrinkage segregation zone in experimental ingots less on 40%.

Structure of experimental and compared commercial ingots has habitual zones for killed steels: columnar dendrites, equiaxed crystal zone and bottom cone of globular dendrites. Width of columnar dendrite zone in microalloyed ingots is practically same. In that time the secondary skeleton axis and interdendritic spaces thickened and rounded off. The globular dendrites are more dispersed than in compared ingot. Original austenite grain size in microalloyed steel is smaller in 2-3 fold.

Optimal quantity of titanium and nitrogen additions caused grain size reducing on 2-3 number in surface zone and on 4-5 number in central zone (here and further - according GOST 5639 requirement). Figure 2 shows the distinguish of grain size in tubular billet from microalloyed (a) and compared (b) steels. We can see that in microalloyed steel the share of ferrite increased. This connected that Ti stabilizes the α-phase.

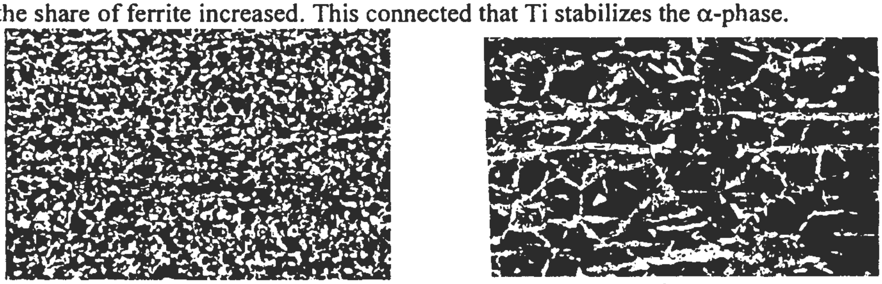


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Figure 2. The metal microstructure of tubular billet from microalloying (a) and compared (b) steels (magnification 50x).

Similar results were obtained for rail steel ingots 8.4 t. However, long duration of crystallization in this case caused to partial removing of Ti-rich non metal inclusions. Distribution of this inclusions is not uniform. In central part of ingots which has most duration of liquid state the quantity of Ti-rich inclusion is minimal. Besides the size of titanium nitrides and carbonitrides from surface to center of ingots increases from 2-5 μm up to 15-20 μm, that connected with temperature and duration of their formation and growth. Despite of this tendency the common size of original austenite grain size reduced in 2-4 fold.

The steel hardness increased on 2-5 HRC due to dispersed strengthening of steel by particle of Ti-containing inclusions. The strength properties of steel also increased (in whole on 25-40 MPa) that bonded with effective counteraction of dispersed precipitations against dislocation moving. It has also been established that plastic properties of steel improved – relative elongation on 3-4 and relative reduction of area on 7-8 units. The impact toughness of microalloying mid carbon steel with optimal Ti and N contents passed heat treatment (double heating) is four folded as much as to compare with usual steel – 125 and 32 J/cm^2,accordingly.The wear resistance of microalloyed rail steels also sufficiently improved.

Draw attention the fact that as in small laboratory as in large commercial ingots the Ti-rich inclusions placed highly arbitrary in attitude to dendrite structure: they situated as in center as on periphery of dendrite axles and in interdendrit space also. Besides, few inclusions can be situated in one dendrite or interdendritic space. It has been found that titanium nitride and carbonitride mainly situteted in ferrite cover (Figure 3).

Figure 3. The titanium carbonitride in ferrite cover (magnification 2000x)

Sometime the particle of titanium nitrides and carbonitrides are the substrate for manganese sulphide formation (Figure 4) and also places in ferrite.

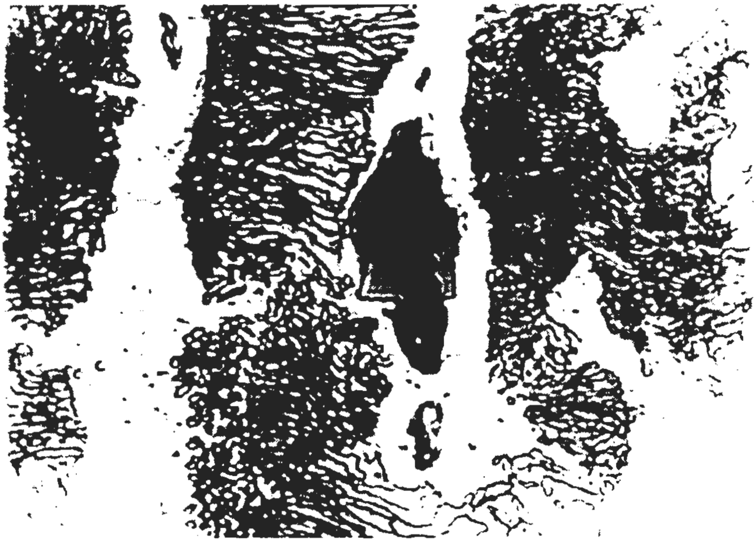

Figure 4. The manganese sulphide formed on titanium carboniride (magnification 1200x)

Such conglomerate always situated in interdendritic spaces and may draws up into lines. The regularity of inclusion situation in attitude of graine structure wasn't found. Such disposition of particles allows to suppose that its fixing occure during all period of metal solidification. The role of Ti-rich particles as heterogeneous nucleation of steel agents in many depends on of crystallization processes pecularities such as cooling rate of metal volume.

Conclusions

Generalization of obtained results shown that titanium addition allow to improve as primary as grain structure of middle-carbon steels. It has been established that sufficient grain refinement was observed when modified metal solidifies rapidly – in small mass and cross section ingots or cast.

Recenzował: dr hab. inż. Tadeusz Mikulczyński, prof. nadzw.