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Application of Continuous Cast Billet in Corrosion-Resistant Steel Tube Making

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Large-scale experiments related to the tube making from high-alloy corrosion-resistant steel TP 304L and TP 316L continuous cast billets have been carried out for the first time in domestic practice. The tubes with a wide dimensional range are produced by means of hot pressing, warm and cold rolling under industrial conditions. The complex estimation of produced tube quality has shown their conformity with ASTM standards.

Keywords: TUBE, CONTINUOUS CAST BILLET, TECHNOLOGY, STRUCTURE, PROPERTIES, QUALITY

Introduction

During last years, there are significant changes in the sphere of corrosion-resistant steel tube making [1-3]. This is related to operating manufactures upgrading, construction of new closed cycle plants, adoption of new kinds of tubular billet and tubes with a wide range of sizes, particularly, under foreign standards. One of the most perspective tendencies to reduce the cost price of tubes at simultaneous maintenance of proper quality is the use of continuous cast billet (CCB). However, the deformed (forged, hot-rolled) billet formed from square or rectangular ingot predominates till now when making high-alloy corrosion-resistant steel tubes. Its production technology is characterized by multicycling with significant power consumption. The structure of this billet is featured by zone inhomogeneity, grains of various size, irregular distribution of both nonmetallic inclusions and ferritic phase over cross-section [3], which complicates the formation of regulated structure and properties of tubes.

Therefore, CCB is widespread in the world. Produced with the use of advanced electrometallurgy, it has the following advantages:

1. relative chemical and structural homogeneity over the cross-section;
2. nonmetallic inclusion and detrimental impurity cleanness;
3. reduction of process cycle and metal losses.

The measures providing CCB quality for tubes are quite various. The most important are: liquid melt blow by mixed gases, mechanical or electromagnetic circulation, casting of ingots with a round cross-section, etc. [4, 5]. All these enable to produce quality billets regarding makeup, structure and surface.

The purpose of this research is to generalize the results of industrial experiments performed at JSC "SENTRAVIS PRODUCTION UKRAINE" concerning tube making from high-alloy corrosion-resistant steel CCB according to requirements of standards ASTM A 312, ASTM A 213, etc.

Methodology

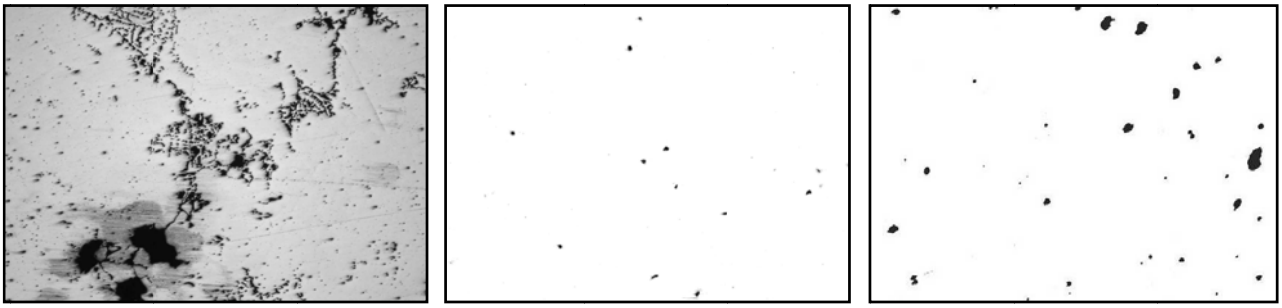
Steels TP304L (analogue 03X18H11) and TP316L (analogue 03X17H14M3) produced by Italy, India, France, were applied for investigations. Following methods were used for steelmaking:

1. continuous casting of billets of rectangular (**Figure 1a**) or square (**Figure 1b**) cross-section with further small deformation for round cross-section formation;
2. directly after continuous casting of round billets with no additional deformation (**Figure 1c**).

Billet diameters were 180, 215 and 250 mm, chemical composition corresponded to requirements of above-mentioned ASTM standards.

a *b* *c*

Figure 1. CCB macrostructure: *a* – steel TP 316 L, ∅ 215 mm, hardening 1.5; *b* – steel TP 304 L, ∅ 215 mm, hardening 3; *c* – steel TP 316 L, ∅ 180 mm, as-cast



a ×100 *b* *c*

Figure 2. CCB microstructure: *a* – defects in the axial zone; *b*, *c* – nonmetallic inclusions

Results and Discussion

There are sections where solidification fronts meet on the cross of crystallizer in the macrostructure of under-deformed billets (**Figure 1a, b**). Thin columnar crystals formed in the section of solidification fronts meeting are a basis in the round CCB (**Figure 1c**). As a whole, the billet macrostructure is compact (except for axial zone, in which pores, microcracks as well as insignificant porosity (**Figure 2a**) are observed and further removed by drilling when preparing tubes for pressing).

Table 1. Results of nonmetallic inclusions estimation in CCB metal on ASTM E45 scale (method A, estimation on the maximum point)

Steel grade, billet size	Supplier	Type A		Type B		Type C		Type D	
		Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
TP 316L, ∅ 215 mm	Italy	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
TP 304L, ∅ 180 mm	Italy	0.0	1.0	0.0	0.0	0.0	0.5	1.0	1.0
TP 304L, ∅ 250 mm	India	0.0 0.5	0.0 0.5	0.0 0.0	0.0 0.5	0.0 0.5	0.5 1.5	4.5 4.5	4.5 3.5
TP 316L, ∅ 180 mm	France	0.5 0.0	0.5 1.0	0.0 0.0	0.0 0.0	0.0 0.5	1.0 0.5	3.0 3.0	3.0 4.0

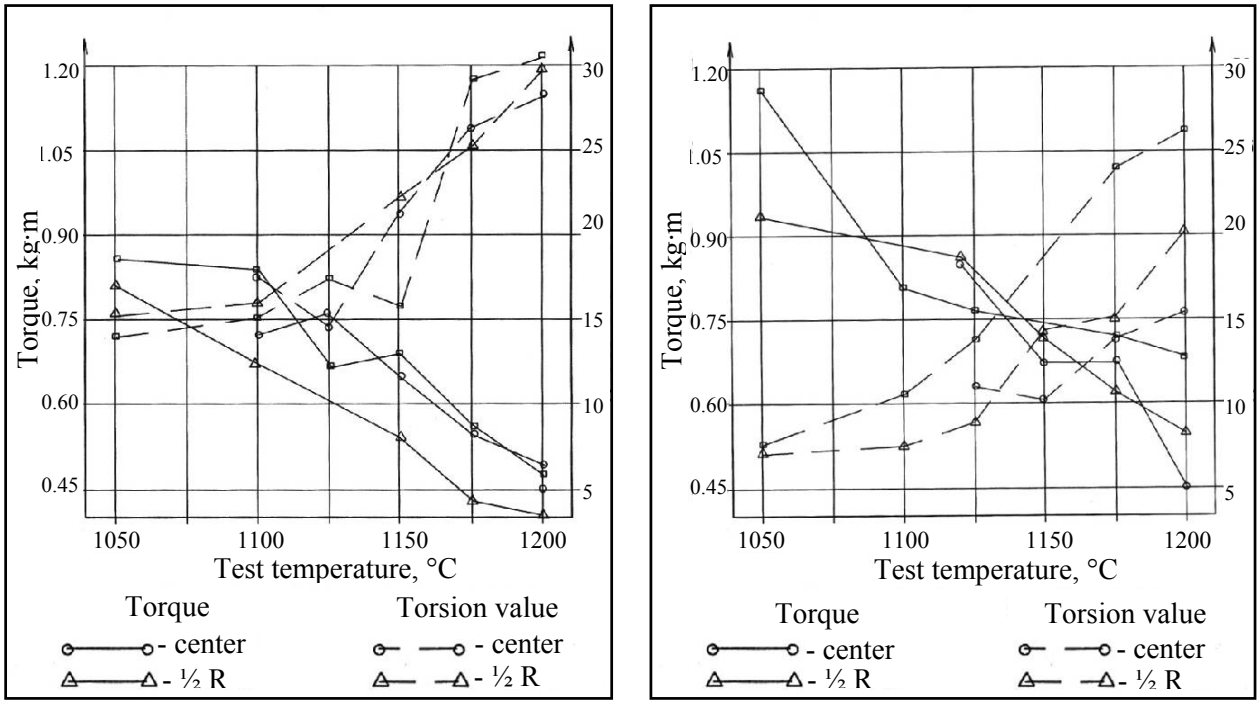
Note: A – sulfides; B – stringer oxides; C – silicates; D – point oxides

We have estimated the nonmetallic inclusion cleanness under ASTM E45 standard. The results are as following: oxides, silicates and sulfides dominate (**Table 1**). There are billets with both reduced nonmetallic inclusion impurity (**Figure 2b**) and their high enough concentration (**Figure 2c**).

Results of mechanical and technological tests have shown that CCB metal is characterized by optimum combination of strength and plastic properties, and can be subjected to further deformation by hot pressing method (**Table 2**). The maximum level of technological ductility of CCB made of steel TP 316L and TP 304L is in the interval 1150-1200 ^{o}C (**Figure 3**).

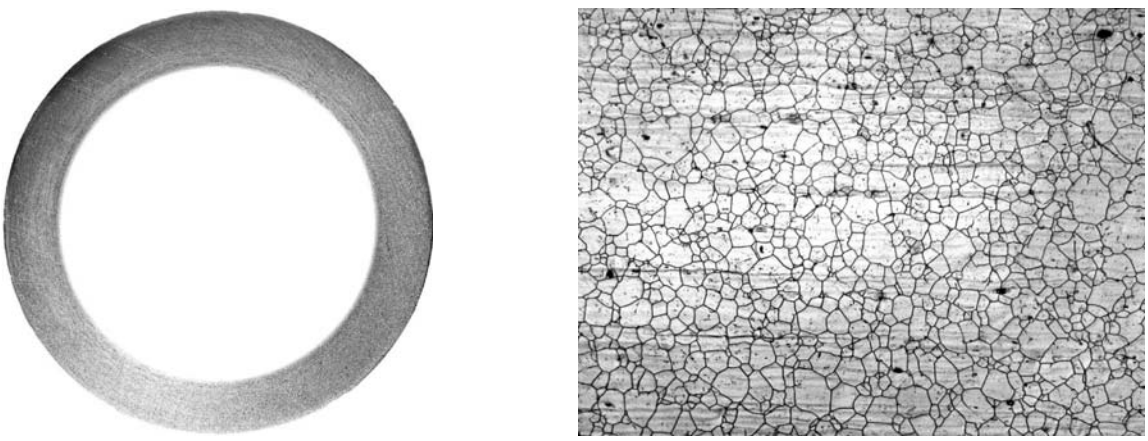
Table 2. Mechanical properties at CCB tension (test temperature = room temperature)

Steel grade	Tensile strength, N/mm^2	Yield strength, N/mm^2	δ_5, %	ψ, %
TP 316 L	446-529	266-370	28-50	40-74
TP 304 L	493-563	272-402	42-55	68-74



a *b*

Figure 3. Change of CCB plastic properties when testing on heat rolling: *a* - steel TP 304L, *b* - steel TP 316 L



a *b* x100

Figure 4. Macrostructure (*a*) and microstructure (*b*) of hot-pressed tubes made of CCB

Hot-pressed tubes made from CCB had the satisfactory surface quality, including shallow scratch marks, folds, compression marks. There were no such major defects as scabs, fractures, etc. Structure of tubes was compact homogeneous and completely recrystallized (**Figure 4**). The rests of not deformed cast structure were not observed.

The next stage of work was a complex estimation of tube quality produced via hot pressing, warm and cold rolling.

All the tubes were NDT inspected and tested for intergranular corrosion. Tubes made of CCB metal met the basic and additional requirements of standards on geometrical sizes, surface quality, level of mechanical properties, grain size and intergranular corrosion resistance (**Table 3**).

Table 3. Mechanical properties of CCB tubes (average values)

Steel grade	Tube size, mm	Tensile strength, N/mm^2	Yield strength, N/mm^2	δ_5, %
Hot-pressed tubes				
TP 316 L	∅ 114×6.3	610	290	55
TP 304 L	∅ 95×14	570	285	57
Standards ASTM A312	–	≥485	≥170	–
Warm- and cold-worked tubes				
TP 316 L	∅ 114×3.05	550	270	61
TP 316 L	∅ 108×4	600	310	54
TP 316 L	∅ 76×7.5	620	340	46
TP 316 L	∅ 45×4.1	620	310	51
TP 304 L	∅ 20×2.5	590	370	45
Standards ASTM A213	–	≥515	≥205	≥35

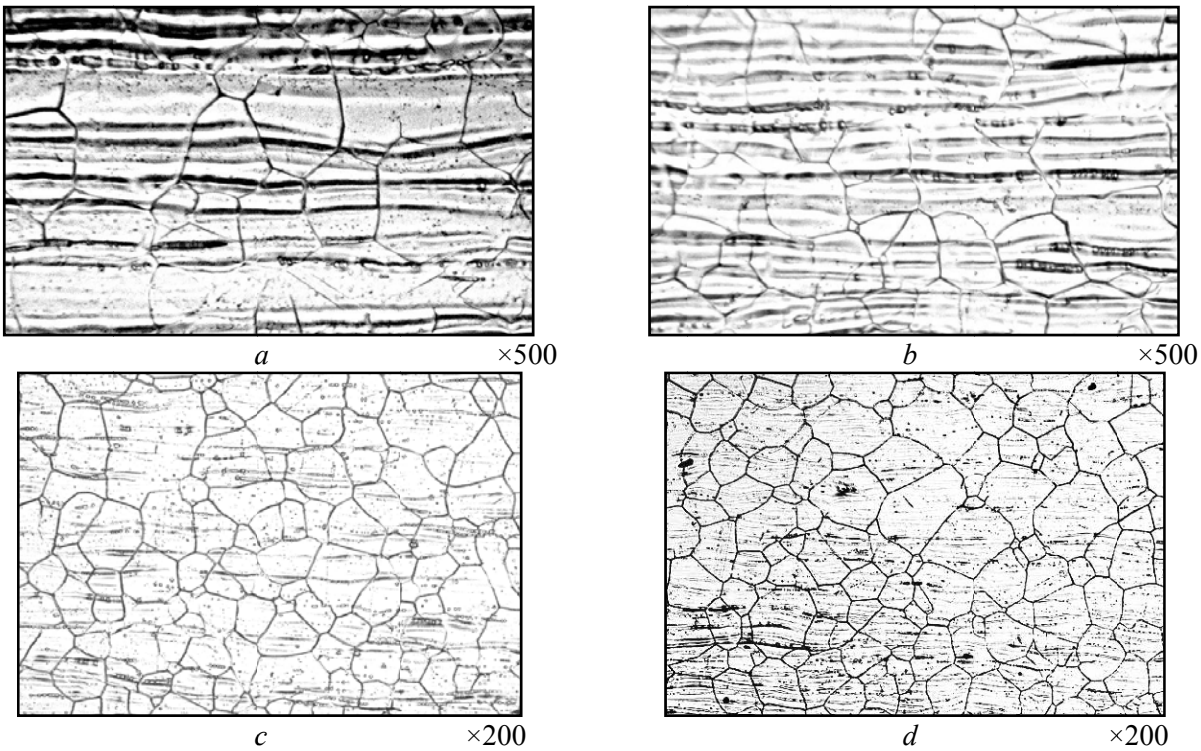


Figure 5. Microstructure of warm - and cold-worked tubes made of CCB (*a, b, c*) and forged blank (*d*) : *a, b* – steel TP 316L; *c, d* – steel TP 304L; *a* – of casting billet (France); *b, c* – of CCB with hardening 1.5 (Italy); *d* – of conventional forged blank

Here, CCB tube microstructure has no vital difference from the microstructure of tubes made from conventional forged blank (**Figure 5**).

Conclusions

1. The possibility of making tubes from high-alloy corrosion-resistant steels TP 304L and TP 316 L CCB has been shown for the first time in domestic practice by results of experiment performed at JSC "SENTRAVIS PRODUCTION UKRAINE".
2. Use of CCB is an effective decision to raise technical and economic indexes of manufacture due to reduction of technological process cycling, decrease of power consumption and cost price of tubes.
3. Quality indicators for CCB from various suppliers ("Cogne Acciai Speciali S.P.A", Italy, "Viragi Profiles Ltd", India, "Arcellor Mittal", France) were estimated. As a whole, the macrostructure of billets is compact homogeneous and consists of columnar crystals. There are defects (micropores and porosity) in the axial zone which were removed during preparation of metal for pressing. Nonmetallic inclusion impurity was within the standard norms 4.5 points. CCB were characterized by a high level of mechanical properties.
4. CCB tubes of a wide dimensional range (hot-pressed, warm - and cold-worked) meet the requirements of standards, in particular, ASTM A 312 and ASTM A 213 on surface quality, geometrical sizes, level of mechanical properties, intergranular corrosion resistance and microstructure.
5. It is reasonable to continue investigating high-alloy corrosion-resistant steel CCB for accumulation of statistical data in order to enter CCB in the standard documentation.

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Использование непрерывнолитой заготовки для производства труб из коррозионностойких сталей

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Впервые в отечественной практике выполнены масштабные эксперименты по производству труб из непрерывнолитой заготовки высоколегированной коррозионностойкой стали TP 304L и TP 316L. В промышленных условиях способами горячего прессования, тёплой и холодной прокатки изготовлены трубы широкого размерного сортамента. Комплексная оценка качества полученных труб показала их соответствие требованиям стандартов ASTM.