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Processing plasticity of metal of nondeformed continuously cast tube billets

The article presents results of studies of processing plasticity (ability to hot working) of metal of nondeformed continuously cast tube billets (CCTB) from carbon steel grades produced by MZ Dniprostal LLC. Processing plasticity of continuously cast billets was studied by testing for hot twisting in the temperature range from 1100 to 1250 °C on State Enterprise “SRTI” equipment. Hot twisting tests were performed with CCTBs having various macrocrystalline structures. Temperature ranges of maximum plasticity of metal of the CCTBs manufactured from carbon steel grades have been determined. Distribution of hot twisting test parameters (the number of twists to failure and the twisting force) over the CCTB cross section has been studied. Influence of macrocrystalline structure on behavior of the CCTB metal during the hot twisting tests was revealed.

The study results are of great scientific and practical importance in the context of ever growing use of CCTBs in production of tubes for various purposes. The results obtained for the first time in the studies of processing plasticity of metal of nondeformed continuously cast tube billets made of carbon steel grades with various macrocrystalline structures will make it possible to recommend optimal temperatures for heating initial CCTBs before hot rolling. Heating continuously cast billets according to optimal temperatures with taking into account their actual macrocrystalline structure will improve plasticity and reduce resistance to deformation of metal of these billets during the piercing process and, accordingly, minimize formation of surface defects in the tubes produced from the CCTBs.

The study results will also serve as a basis for improving the CCTB manufacture technology at MZ Dniprostal LLC in order to obtain a macrocrystalline structure of the billet metal which will ensure a satisfactory level of processing plasticity as well as a more uniform distribution of plastic properties over the CCTB section.

Key words: nondeformed continuously cast tube billet, macrocrystalline structure, columnar crystals, equiaxial mis-oriented crystals, processing plasticity, hot twisting tests, number of twists to failure, twisting force.

As a rule, hot-worked tubes are produced by hot rolling using various tube-rolling units incorporating a continuous mill, a pilgrim mill, an automatic mill or a three-roll reeling mill [1–3]. For reliable operation, these tubes must meet all requirements of regulatory documents including quality of the outer and inner surfaces. Piercing of a preheated initial tube billet [3–5] is one of the main operations in the process flowsheet of manufacturing hot-rolled tubes on any of the above units. As is known, violation or imperfections of the process of billet heating before piercing lead to formation of unacceptable defects of a tube-rolling origin [6–8]. To exclude formation of defects in shells and, accordingly, in the finished tubes, metal of the tube billet should have

a sufficiently high plasticity and low resistance to deformation which, taken as a whole, determine processing plasticity of the billet metal [9–12]. To determine processing plasticity of the billet metal, high-temperature tests are used, in particular, hot twisting tests which make it possible to determine the temperature range in which the billet metal has maximum plasticity. Processing plasticity depends on temperature, ratio and schedule of deformation, chemical composition and structural state of the tube billet metal [12–15].

Recently, the enterprises producing hot-worked tubes are beginning to use nonworked continuously cast billets (CCBs) along with conventional worked tube billets obtained from stationary or continuously cast ingots.

Interpipe Niko Tube LLC is one of such enterprises having the ability to use CCBs manufactured by MZ Dniprostal LLC which, like Interpipe Niko Tube LLC, is a part of the Interpipe Corporation.

However, temperatures to which the billets are heated before hot rolling experimentally established for worked tube billets and tested for many years at Interpipe Niko Tube are not fully suitable for the CCBs remarkable for their dendritic chemical and structural heterogeneity [16–18]. The use of conditions of CCB heating before piercing adapted only for worked billets can lead to formation of defects (including hidden ones) of varying degrees of roughness of the finished tube surface which become apparent only during the tube operation.

To determine an optimal temperature range of heating before piercing the nonworked continuously cast tube billets of carbon steel grades which ensures maximum plasticity of the billet metal under conditions of a complex stressed state during hot deformation and, accordingly, reduce likelihood of formation of defects on the tube surface, it is necessary to conduct a study of processing plasticity of such billet metal.

The study object included 210 mm dia. CCBs made of 10U and 20U steel grades (according to MZ Dniprostal

LLC Grade Nomenclature and 150 mm dia. CCBs of '20' boiler steel grade (according to Technical Specification

Fig. 1. Macrostructure of metal of the CCBs made of 10U (a), '20' (b) and 20U (c) steel grades, $\times 0.3$

Fig. 2. Dependence of average values of the number of twists n (a) and deformation force P_{cr} (b) on test temperature for the CCBs made of 10U steel grade

Fig. 3. Dependence of average values of the twist number n (a) and deformation force P_{cr} (b) on test temperature for the CCBs made of '20' steel grade

Fig. 4. Dependence of average values of the twist number n (a) and deformation force P_{cr} (b) on the test temperature for the CCBs made of 20U steel grade

TU U 24.1-05757883-216). Chemical composition of metal of the CCBs under study met the requirements of regulatory documents and corresponded to chemical composition of the metal of conventionally used worked billets of similar steel grades from other manufacturers.

Hot twisting tests were conducted using an SMEG-10T machine according to the procedure of NITI State Enterprise (RMI 247-13) in a temperature range of 1100 to 1250 °C.

Macrocrystalline structure of the billets undergoing the tests was assessed on transverse templates after their deep etching in a 50 % aqueous solution of HCl at 60–70 °C. To study plastic properties in the CCB cross section, specimens were cut from the billets in axial and intermediate zones.

The study results. The continuously cast billets under study are notable for their macrocrystalline structure determined by the technological factors of their casting.

Macrocrystalline structures of metal of the CCBs made of 10U steel grade and '20' boiler steel grade were identical and characterized by presence of developed zones of columnar crystals (transcrystallization) occupying an area of up to 90 % relatively evenly distributed and symmetrically located in the billet cross section (Fig. 1, a, b). Metal of the CCBs made of '20' steel grade differed from that of the billets made of the above two steel grades by

presence of an asymmetrically located zone of equiaxed crystals (up to 30 % area) and a zone of transcrystallization in a form of misoriented columnar crystals of various degrees of roughness and length radially located with a slight turn about the axis (Fig. 1, c).

The results obtained in hot twisting tests of continuously cast billets are presented in Figs. 2–4 by curves of dependence of average twist number values and twisting forces on the test temperature and indicate influence of macrocrystalline structure of the continuously cast metal on distribution of plastic and force characteristics in the section of the billets under study.

The following regularity can be traced in distribution of plastic properties over the billet section for the CCB metal with a developed transcrystallization zone, regardless of the steel grade (10U steel grade or '20' boiler steel grade) and diameter (210 mm or 150 mm). The number of twists before fracture of the specimens cut from the intermediate zone at all temperatures studied was less than the corresponding figures for the specimens cut from the axial zone. Moreover, there was a sharp increase (~40 %) in the number of the specimen twists before failure for the intermediate zone beginning from 1200 °C. The curves of dependence of the twist number on temperature for the specimens cut from different cross section zones of these billets (axial and intermediate) had a similar form with a pronounced maximum at 1225–1230 °C. A tendency to a decrease in the deformation (twisting) force in the studied temperature range was observed for the metal of axial and intermediate zones of the mentioned CCBs while values of the deformation force differed insignificantly in the temperature range of 1150–1250 °C for the metal of the same zones. The smallest value of the deformation force was obtained both for the axial and intermediate zones at a test temperature of 1250 °C. For the studied CCBs characterized by presence of a developed zone of columnar crystals in the metal macrostructure, heating before piercing is recommended to be carried out in the tube processing to a temperature of 1200–1250 °C.

When testing for hot twisting of specimens of the CCBs made of 20U steel grade which have a macrocrystalline structure different from the above-mentioned billets, a lower level of force and plastic characteristics and a fundamentally different regularity of their distribution over the billet cross-section were obtained. The curves of dependence of the number of twists on temperature for the specimens taken from different zones of the billet cross-section have different forms. This curve has a pronounced maximum corresponding to temperature of 1200 °C for the axial zone. For the intermediate zone, the number of specimen twists sharply increases up to the specimen failure beginning from this temperature to the limiting test temperature (1250 °C). The curve of dependence of the number of twists on temperature is of incomplete nature. Deformation forces for the specimens taken from the axial zone of a CCD made of 20U steel grade practically are higher than those for the specimens taken from the intermediate zone in the entire temperature range under study with an exception of the temperature of 1200 °C at which values of this indicator are

the same for different metal zones. The smallest value of the deformation force was observed at test temperature of 1225 °C for the axial zone and at 1200 °C for the intermediate zone. Besides, against the background of the general tendency of decrease in the deformation force with an increase in test temperature, an anomalous increase in the deformation force was observed at 1175 °C for the specimens cut from both axial and intermediate zones. Such ambiguous results obtained in the twist tests of the specimens taken from the CCMs made of 20U steel grade are explained by peculiarities of the steel structure state as well as by the place of taking specimens that necessitates further studies. Moreover, taking into account the incomplete character of the curve of dependence of the number of twists of the specimens from the intermediate zone on temperature when conducting studies of the processing plasticity of the CCB metal, it is necessary to raise maximum of the twisting test temperature up to 1300 °C.

Conclusions

1. Influence of the macrocrystalline structure on processing plasticity of metal of nonworked continuously cast billets made of carbon steel grades was confirmed. A difference in behavior of various zones in the CCB cross section in the course of hot twisting tests was established.

2. Optimal temperature interval of heating before piercing (in the process of tube processing) the continuously cast billets made of carbon steel grades having the metal macrostructure characterized by presence of a developed zone of columnar crystals relatively evenly distributed over the billets cross section has been determined.

3. It was shown that it is necessary to continue studies of the processing plasticity of metal of the continuously cast billets having different macrocrystalline structures in order to minimize formation of defects in tubes production.

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Технологічна пластичність металу недеформованих безперервнолитих трубних заготовок

В статті наведено результати досліджень технологічної пластичності (здібності до гарячого деформування) металу недеформованих безперервнолитих трубних заготовок (БЛЗ) з вуглецевих марок сталі виробництва ВАТ «МЗ «ДНІ-ПРОСТАЛЬ». Технологічну пластичність безперервнолитих заготовок досліджували шляхом проведення випробувань на гаряче скручування в інтервалі температур від 1100 до 1250 °С на обладнанні ДП «НДТІ». Випробуванням на гаряче скручування піддавали БЛЗ, які мають різну макрокристалічну будову. Визначено температурні інтервали максимальної пластичності металу з вуглецевих марок сталі. Досліджено розподіл показників випробувань на гаряче скручування (число скручувань до руйнування та зусилля скручування) по перетину БЛЗ. Виявлено вплив макрокристалічної будови на поведінку металу БЛЗ в процесі випробувань на гаряче скручування.

Результати досліджень мають важливе наукове та практичне значення в умовах все більш широкого застосування БЛЗ для виробництва труб різного призначення. Вперше отримано результати досліджень технологічної пластичності металу недеформованих безперервнолитих заготовок з вуглецевих марок сталі з різною макрокристалічною будовою, які дозволяють рекомендувати оптимальні температури нагріву вихідних БЛЗ перед гарячою прокаткою. Нагрів безперервнолитих заготовок за оптимальних температур, з розрахунком їх фактичної макрокристалічної будови, дозволить збільшити пластичність і зменшити спротив деформуванню металу цих заготовок в процесі прошивки і мінімізувати утворення дефектів поверхні труб, які виготовлені з БЛЗ.

Результати досліджень також послужать підставою для удосконалення технології виготовлення БЛЗ на ВАТ «МЗ «ДНІ-ПРОСТАЛЬ» з метою отримання макрокристалічної будови металу заготовок, яка забезпечить задовільний рівень технологічної пластичності, а також – більш рівномірний розподіл пластичних властивостей по перетину БЛЗ.

Ключові слова

Недеформована безперервнолита трубна заготовка, макрокристалічна будова, стовпчасті кристали, рівноосні розорієнтовані кристали, технологічна пластичність, випробування на гаряче скручування, кількість скручувань до руйнування, зусилля скручування.