Crossref
UDC 669.1.017
DOI: 10.31643/2021/6445.14

IRSTI 53.49.13

Comparative analysis of the structure of solid and hollow steel cast billets

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Received: *28 February 2021*
Peer reviewed: *10 March 2021*
Accepted: *04 May 2021*

ANNOTATION
This paper presents the research results of solid structure and hollow steel billets obtained by continuous casting. To substantiate the feasibility of using a hollow billet as an initial one in the production of seamless hot-rolled pipes, a comparative analysis of the distribution of non-metallic inclusions, macro- and microstructure, as well as segregation by structural zones was carried out. When analyzing the macrostructure of a hollow billet, two distinct zones were revealed: equiaxed small and columnar crystals, which distinguishes it, compared with a solid billet, by the absence of a zone of misoriented crystals. This, in turn, helps to eliminate defects such as axial porosity and segregation. The improved quality of the macrostructure during casting of a hollow billet is explained by more favourable conditions for heat removal and a higher rate of solid-phase advance due to bilateral cooling, and less shrinkage of the melt due to its cross-sectional geometry. The distribution of nonmetallic inclusions, consisting of oxide, sulfide and oxysulfide compounds, and liquidation elements, showed that they are concentrated mainly at the boundaries of crystalline zones, and for a solid billet and in the central part. This fact is caused by the development of a zone of intense heat removal. When research the microstructures of solid and hollow workpieces, a ferrite-pearlite mixture is observed in both cases. The microstructure of the hollow billet is more dispersed, which is confirmed by durometric measurements.

Keywords: continuous casting, liquation, macrostructure, non-metallic inclusions.

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Introduction

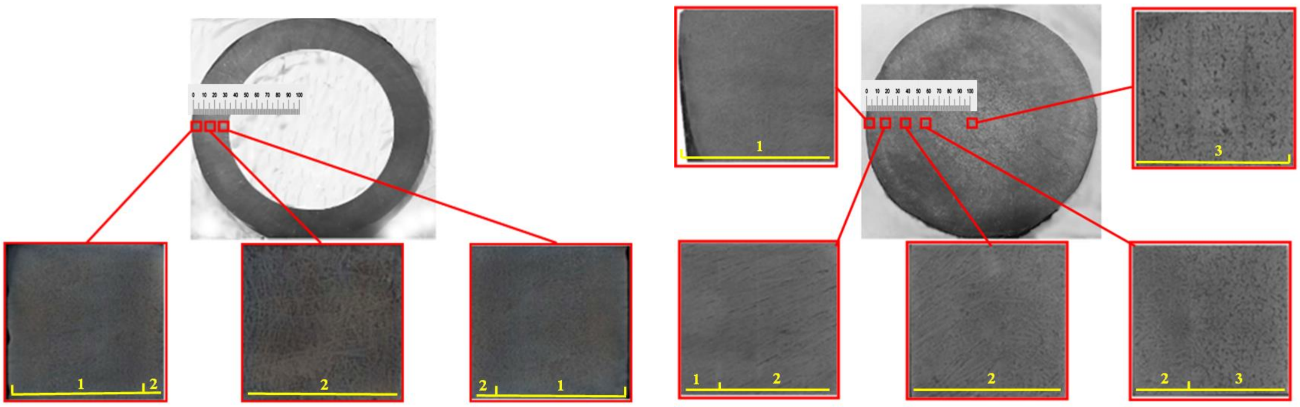
The increasing requirements of the oil and gas industry to the level of pipe products properties requires intensification of work to improve the technological properties and quality indicators of continuously cast billets. To solve these problems, pipe manufacturers are introducing modern production technologies and modernizing equipment [1-6].

One of the effective methods for improving the quality of pipe products is using a hollow billet as an initial one. This will improve the quality, in particular, almost wholly eliminate axial porosity and segregation. Also, due to the presence of a cavity in the billet, it is possible to use double-sided cooling, which promotes better conditions for the crystallization of the melt and an increase in the productivity of continuous casting machines [6-13].

In connection with the above, the purpose of this work was to research the formation of the macro- and microstructure of hollow and solid billets and analyze the distribution of non-metallic inclusions and liquidation elements.

Material and research methods

The research object is billets from steel 09G2S: solid Ø 210 mm and hollow Ø 210×140 mm. The billets under research were cast into sand molds 250 mm high to exclude the effect of end cooling, in one of which a rod was used to form an internal cavity. After casting, templates were cut from the



1 – zone of equiaxed small crystals; 2 – zone of columnar crystals; 3 – zone of misoriented crystals

Figure 1 – Macrostructure of solid and hollow billets

billets at a distance of 100 mm from the end to analyze the structure and chemical composition.

The macrostructure and the degree of development of internal defects were determined according to GOST 10243-75 "Steel. Test methods and evaluation of macrostructure" after etching in 50% HCl solution at a temperature of 60° C for 40 minutes. Microstructures were researched by GOST 8233-86 "Steel. Microstructure Standards". Preparation of thin sections for work on a microscope was carried out according to a technique that included surface polishing, etching of thin sections in a 20% aqueous solution of HNO_3. The microstructure was revealed by etching in a 4% HNO_3 solution. The study of the microstructure was carried out using an Olympus BX53M microscope by optical metallography.

To assess the liquation, the chemical composition was determined on an optical emission spectrometer SPECTROMAXx by the spectral method according to GOST R 54153 "Steel. Method of atomic emission spectral analysis".

Determination of contamination and identification of nonmetallic inclusions was carried out on microsections sampled over the billets section using optical microscopy on Olympus BX53M and X-ray spectrometry using a multichannel spectrometer CPM 25. Contamination of the microsections was assessed separately for oxide, sulfide and oxysulfide inclusions. The calculation of contamination with non-metallic inclusions was carried out by GOST 1778-70 "Metallographic methods for the determination of non-metallic inclusions" (method L).

Durometric research of microstructures were carried out using a PMT-3 microhardness tester with a load of 20-100 g.

Research results and discussion

Macrostructure. The main structural zones characterize the macrostructure of the templates under research (Figure 1): the cortical zone, the zone of columnar crystals, and for a solid billet, there is also a zone of misoriented crystals.

The zone of small equiaxed crystals consists of crystallites with a short length, a solid billet 18 mm, and a hollow billet 8-9 mm. An increase in the thickness of the solidifying layer, due to the formation of a developed cortical zone, leads to a decrease in the solid phase advance intensity. Simultaneously, the value of the temperature gradient remains sufficiently high, which leads to the formation of elongated columnar crystals. The lengths of columnar crystals zones for solid and hollow blanks are 30 mm and 22 mm, respectively.

The absence of a pronounced zone with misoriented crystals in a hollow billet indicates an improvement in the cooling effect's efficiency on the surface of continuously cast billets during casting in comparison with a solid billet.

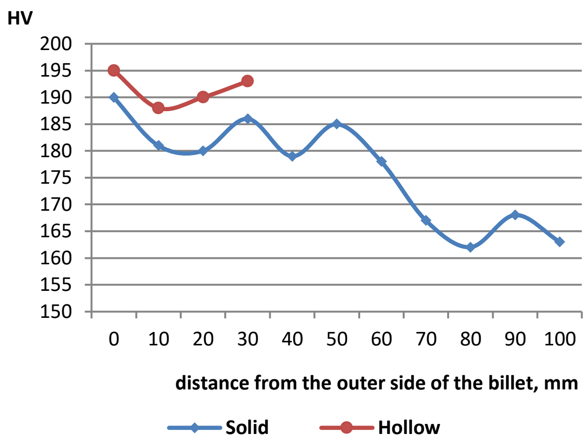


Figure 2 – Microhardness of billets

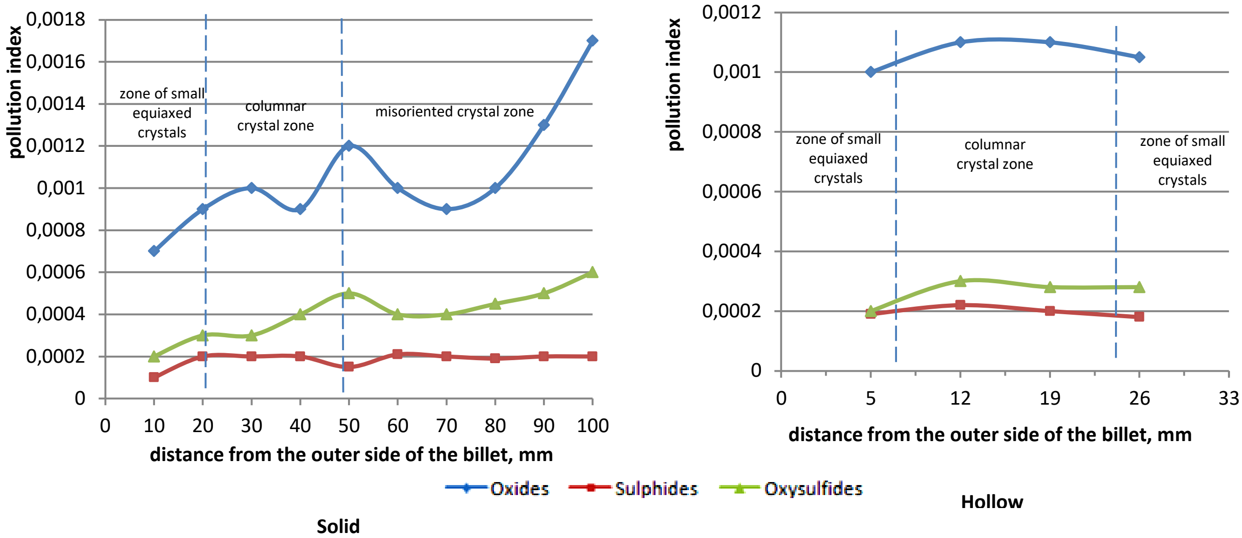


Figure 3 – Distribution of non-metallic inclusions over the section of the billet

The obtained macrostructures during casting of a hollow billet confirm more favourable conditions for heat removal, a greater intensity of solid-phase advance, and a more homogeneous steel structure.

Durometric studies were carried out to assess the homogeneity of the structure of templates of solid and hollow blanks. Figure 2 shows the measurement results.

The microhardness values at a load of 25 g confirm a more homogeneous structure for the hollow blank.

Non-metallic inclusions. Analysis of non-metallic inclusions identified by X-ray spectrometry showed the presence of oxide (Al_2O_3), sulfide (CaS) and oxysulfide ($Al_2O_3 \cdot CaS$) compounds, the cause of which is the use of deoxidizers (Al) and modifying additives (Ca).

The distribution of non-metallic inclusions over the billet section is shown in Figure 3.

Analysis of the distribution of nonmetallic inclusions over the cross-section of a solid billet showed that the distribution is of a hopping pattern associated with the conditions for changing heat removal and changing crystalline zones.

The results, in Figure 3, show that the content of inclusions increases when approaching the centre of the billet, but this increase is not monotonic. At a distance of 45-50 mm from the edge of the solid billet, corresponding to the columnar crystals zone's boundary, the content of oxide and oxysulfide inclusions increases, then, as the billet axis approaches, the range of inclusions reaches its maximum value. The uneven distribution of non-metallic inclusions is due to the solidification features of the misoriented crystals zone. A decrease in the temperature gradient due to a reduction in the solid phase advance intensity causes the intensive development of liquation.

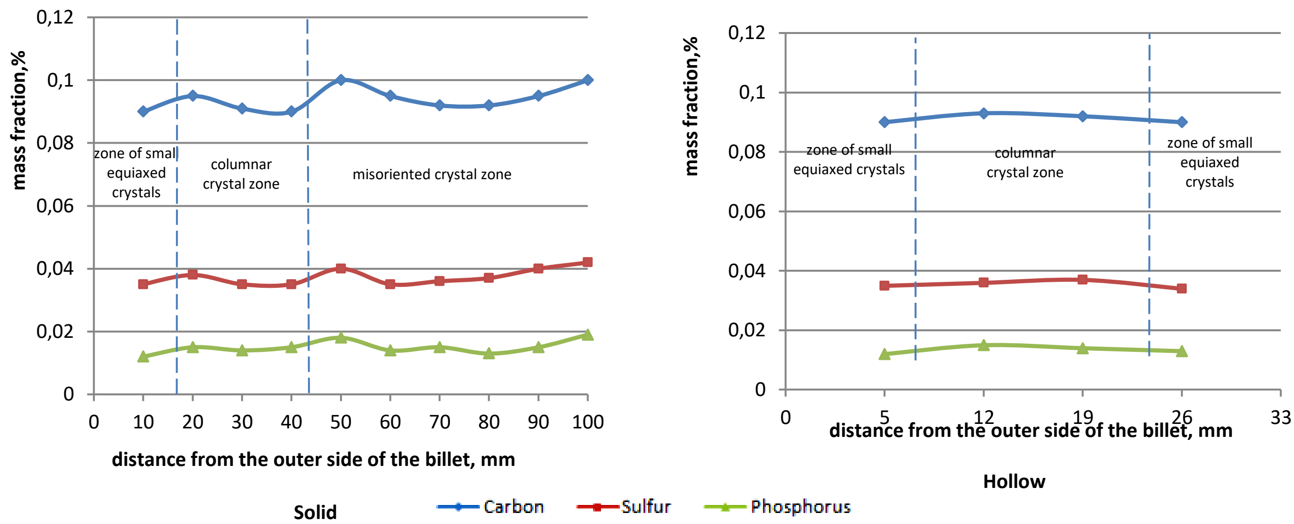


Figure 4 – Distribution of liquidation elements over the section of the billet

Analyzing the hollow billet structure, it can be noted that there is a uniform distribution of all types of non-metallic inclusions. This indicates a higher rate of solid-phase advance due to double-sided cooling and lower billet section values.

Chemical heterogeneity. To research the processes of segregation of continuously cast billets, spectral chemical analysis was carried out with a given distance of at least 12 mm, taking into account the burnout diameter of 10 mm. Figure 4 shows the results of spectrometric analysis.

Surface layers of continuously cast billets, solidified under intensive solid-phase advance conditions, have a more uniform distribution of elements and a low degree of segregation. A change in the chemical composition of liquidating impurities is observed in the case of a solid billet when passing through the boundaries of crystalline zones.

In the central part of the solid billet, an increase in all elements' concentration was recorded. An increase in chemical inhomogeneity in the axial part of continuously cast billets is explained by a change in the conditions of heat removal and the formation of equiaxed crystals zone, which solidifies under conditions of a minimum temperature gradient and maximum concentration overcooling.

Regarding the change in the content of liquidating elements over the hollow billet section, it should be noted that liquation appears insignificantly due to the significant development of the intense heat removal zone.

Microstructure. The research of hollow and solid billets microstructures showed a ferrite-pearlite structure (Figure 5).

A solid billet, ferrite (F), and pearlite (P) grains have an irregular shape with sharp corners. An increase in the size of ferrite and pearlite grains is observed along the section of the billet. The phase components' shape changes from more equiaxed in the cortical zone to elongated in the dendrite zone and polygonal in the axial part of the billet.

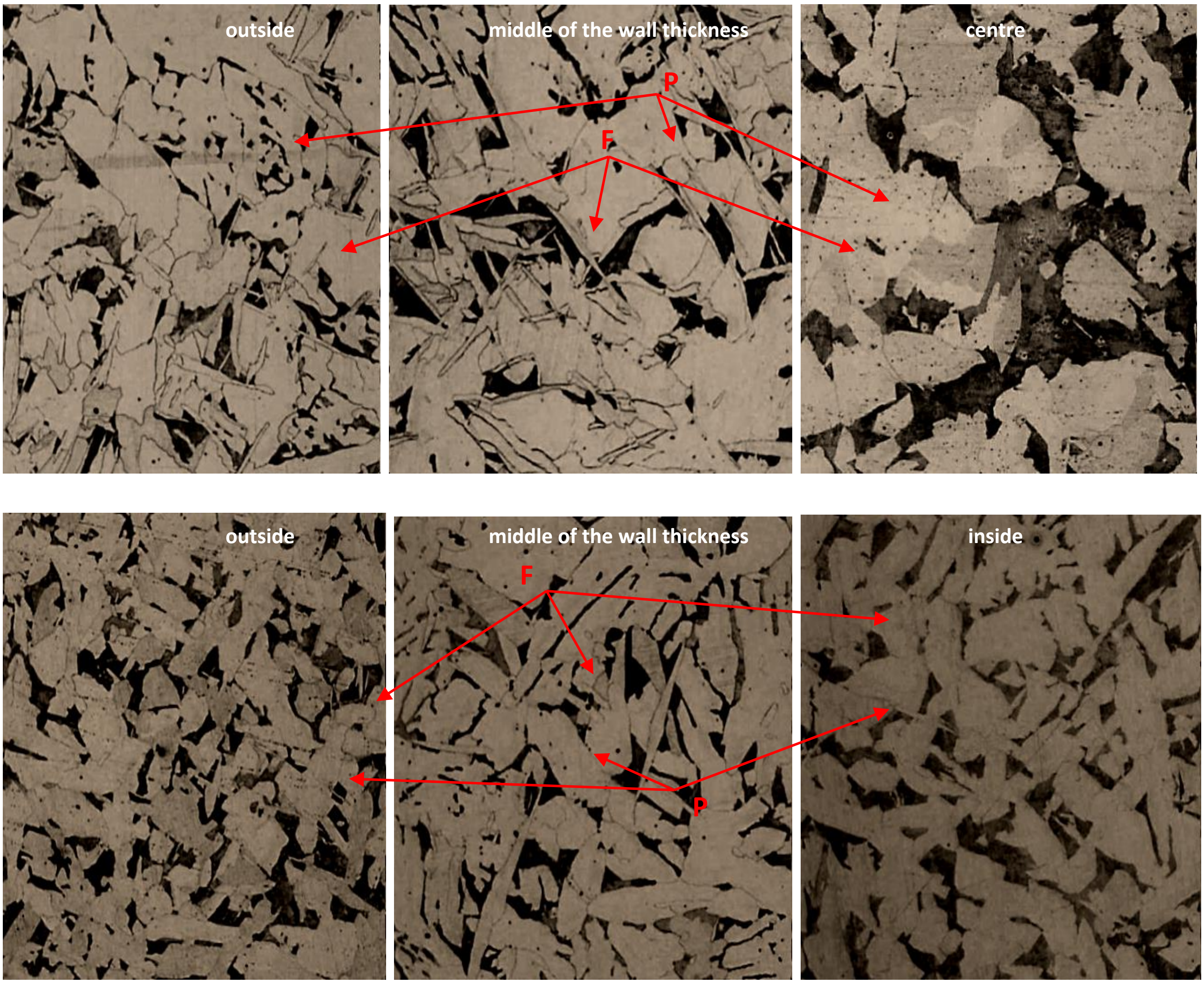


Figure 5 – Microstructures of billets (×100)

Both cases are characterized by acicular ferrite in the form of Widmanstatten ferrite, which is formed with a significant degree of liquid metal overcooling and differing in the degree of ferrite dispersion. The cast billets' obtained microstructures confirm the change in the values of the previously presented microhardness results.

Conclusion

The research results confirmed the improvement in the structure of the hollow billet after casting in comparison with the solid one. Simultaneously, the absence of the billet central part allows avoiding the occurrence of such defects as axial porosity and segregation. Microstructure analysis showed a more dispersed structure in the hollow billet due to better cooling conditions. A more favourable distribution of non-metallic inclusions and liquidation elements is also observed in the hollow billet. Thus, the purpose of the research was achieved and the feasibility of using a hollow billet for the production of seamless oil and gas pipes was confirmed.

Conflict of interest. On behalf of all authors, the corresponding author declares that there is no conflict of interest.

Cite this article as: Zhakupova A.T., Salina V.A. Comparative analysis of the structure of solid and hollow steel cast billets. *Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a. = Complex Use of Mineral Resources = Mineraldik Shikisattardy Keshendi Paidalanu.* 2021. №2 (317), pp. 23-29. https://doi.org/10.31643/2021/6445.14

Тұтас және қуыс болат құймалар дайындамаларының құрылымын салыстырмалы талдау

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Мақала келді: *28 ақпан 2021*
Рецензенттен өтті: *10 наурыз 2021*
Қабылданды: *04 мамыр 2021*

ТҮЙІНДЕМЕ
Бұл жұмыста үздіксіз құю нәтижесінде алынған тұтас және қуыс болат дайындамалардың құрылымын зерттеу нәтижелері келтірілген. Жіксіз ыстықтай прокатталған құбырлар өндірісінде қуыс дайындаманы бастапқы ретінде пайдалану орындылығын негіздеу үшін бейметалл кірінділердің, макро- және микроқұрылымдардың таралуына, сондай-ақ құрылымдық аймақтар бойынша ликвацияға салыстырмалы талдау жүргізілді. Қуыс дайындаманың макроқұрылымын талдау кезінде екі айқын аймақ анықталды: тең осьті ұсақ және бағаналы кристалдар, бұл оны қатты дайындамамен салыстырғанда, бағытталған кристалдар аймағының болмауымен ерекшелендіреді. Бұл өз кезегінде осьтік кеуектілік пен ликвация сияқты ақауларды жоюға көмектеседі. Қуыс дайындаманы құю кезінде макроқұрылымның жақсартылған сапасы жылу берудің неғұрлым қолайлы жағдайларымен және екі жақты салқындату және балқыманың көлденең қимасының геометриясына байланысты аз шөгуі есебінен қатты фазаның жылжу қарқындылығымен түсіндіріледі. Оксидті, сульфидті және оксисульфидті қосылыстардан тұратын бейметалл кірінділердің, сондай-ақ ликвацияланатын элементтердің таралуы олардың негізінен кристалды аймақтардың шекараларында, ал тұтас дайындама үшін және орталық бөлігінде шоғырланғанын көрсетті. Бұл факт қарқынды жылу шығару аймағының дамуына байланысты. Тұтас және қуыс дайындамалардың микроқұрылымдарын зерттеу кезінде екі жағдайда да феррит-перлит қоспасы байқалады. Қуыс дайындаманың микроқұрылымы үлкен дисперсиямен сипатталады, бұл дюрометриялық өлшемдермен расталады.
Түйін сөздер: үздіксіз құю, ликвация, макроқұрылым, бейметалл кірінділер.

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Сравнительный анализ структуры сплошных и полых стальных литых заготовок

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Статья поступила: *28 февраля 2021*
Рецензирование: *10 марта 2021*
Принята в печать: *04 мая 2021*

АННОТАЦИЯ

В данной работе приведены результаты исследования структуры сплошных и полых стальных заготовок, полученных непрерывной разливкой. Для обоснования целесообразности применения в качестве исходной, при производстве бесшовных горячекатаных труб, полой заготовки, проведен сравнительный анализ распределения неметаллических включений, макро- и микроструктуры, а также ликвации по структурным зонам. При анализе макроструктуры полой заготовки выявлено две ярко выраженных зон: равноосных мелких и столбчатых кристаллов, что отличает ее, в сравнении со сплошной заготовкой, отсутствием зоны разориентированных кристаллов. Это, в свою очередь, способствует исключению таких дефектов, как осевая пористость и ликвация. Улучшенное качество макроструктуры при разливке полой заготовки объясняется более благоприятными условиями теплоотвода и большей интенсивностью продвижения твердой фазы за счет двустороннего охлаждения и меньшей усадки расплава ввиду ее геометрии поперечного сечения. Распределение неметаллических включений, состоящих из оксидных, сульфидных и оксисульфидных соединений, а также ликвирующих элементов, показало, что они концентрируются в основном на границах кристаллических зон, а для сплошной заготовки и в центральной части. Данный факт вызван развитием зоны интенсивного теплоотвода. При исследовании микроструктур сплошной и полой заготовок в обоих случаях наблюдается ферритно-перлитная смесь. Микроструктура полой заготовки отличается большей дисперсностью, что подтверждено дюрометрическими измерениями.

Ключевые слова: непрерывная разливка, ликвация, макроструктура, неметаллические включения.

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