ТОРАЙҒЫРОВ УНИВЕРСИТЕТІНІҢ
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
ТОРАЙГЫРОВ УНИВЕРСИТЕТА

ҚАЗАҚСТАН ҒЫЛЫМЫ МЕН ТЕХНИКАСЫ

2001 ЖЫЛДАН БАСТАП ШЫҒАДЫ

TORAIGHYROV
UNIVERSITY

НАУКА И ТЕХНИКА КАЗАХСТАНА

ИЗДАЕТСЯ С 2001 ГОДА

ISSN 2788-8770

№ 4 (2023)

ПАВЛОДАР

НАУЧНЫЙ ЖУРНАЛ
ТОРАЙГЫРОВ УНИВЕРСИТЕТ
выходит 1 раз в квартал

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агенства и сетевого издания
№ KZ51VPY00036165

выдано
Министерством информации и общественного развития
Республики Казахстан

Тематическая направленность
Публикация научных исследований по широкому спектру проблем
в области металлургии, машиностроения, транспорта, строительства,
химической и нефтегазовой инженерии, производства продуктов питания

Подписной индекс – 76129

https://doi.org/10.48081/PWGH3542

Импакт-фактор РИНЦ – 0,210

Импакт-фактор КазБЦ – 0,406

Абишев Кайратолла Кайроллинович – к.т.н., профессор (главный редактор);
Касенов Асылбек Жумабекович – к.т.н., профессор (заместитель главного редактора);
Мусина Жанара Керейовна – к.т.н., профессор (ответственный секретарь);
Шокубаева Зауреш Жанатовна – технический редактор.

Члены редакционной коллегии:
Калиакпаров Алтай Гиндуллинович – д.т.н., профессор (Нур-Султан, Казахстан);
Клецель Марк Яковлевич – д.т.н., профессор (Павлодар, Казахстан);
Шеров Карибек Тагаевич – д.т.н., профессор (Караганда, Казахстан);
Богомолов Алексей Витальевич – к.т.н., ассоц. профессор (Павлодар, Казахстан);
Кажибаева Галия Тулеуевна – к.т.н., профессор (Павлодар, Казахстан);
Зарубежные члены редакционной коллегии:
Baigang Sun – профессор (Пекин, Китай);
Gabriele Comodi – PhD, профессор (Анкона, Италия);
Jianhui Zhao – профессор (Харбин, Китай);
Khamid Mahkamov – д.т.н., профессор (Ньюкасл, Великобритания);
Magin Lapuerta – д.т.н., профессор (СьюДад Реал, Испания);
Mareks Mezitis – д.т.н., профессор (Рига, Латвия);
Petr Bouchner – PhD, профессор (Прага, Чехия);
Ronny Berndtsson – профессор (Лунд, Швеция);
Барзов Александр Александрович – д.т.н., профессор (Москва, Россия);
Витвицкий Евгений Евгеньевич – д.т.н., профессор (Омск, Россия);
Иванчина Эмилия Дмитриевна – д.т.н., профессор (Томск, Россия);
Лазарев Владислав Евгеньевич – д.т.н., профессор (Челябинск, Россия);
Мягков, Леонид Львович – д.т.н., профессор (Москва, Россия);
Янюшкин Александр Сергеевич – д.т.н., профессор (Чебоксары, Россия)
Ребезов Максим Борисович – д.с/х.н., профессор (Москва, Россия).

За достоверность материалов и рекламы ответственность несут авторы и рекламодатели
Редакция оставляет за собой право на отклонение материалов
При использовании материалов журнала ссылка на журнал «Наука и техника Казахстана» обязательна

© Торайгыров университет

SRSTI 53.47.01
https://doi.org/10.48081/CBPX3907

***A. T. Zhakupova[1], A. N. Zhakupov[2]**
[1,2]Toraighyrov University, Republic of Kazakhstan, Pavlodar
*e-mail: aray_zhakupova86@mail.ru

CAST HOLLOW BILLET STRUCTURE SIMULATION MODELING FOR OIL GRADE PIPES

Simulation modeling of hollow billet casting processes for the production of seamless oil grade pipes was performed. The aim of the work was to study the influence of geometric shape on the quality and properties of a continuously cast pipe billet. Modeling parameters, initial and boundary conditions were selected taking into account the conditions of the current production. The object of the study was a pipe billet with a diameter of 210 mm. When modeling the process of casting and solidification of billets, low-alloy structural chromium-molybdenum steel was used. For the simulation processes, three-dimensional models of billets were created, as well as models of shapes. Several factors were taken into account when modeling continuous casting and crystallization of a hollow billet: casting speed, chemical composition of the alloy being poured; casting temperature; geometric dimensions of the billet section. Modeling of hollow billet casting in the «LVM Flow» software package predicted the non-shrinking structure formation a decrease in microporosity (more than 0.85 according to the Niyama criterion) of the billet. As a result of simulation modeling, the improvement of the structure is theoretically confirmed when using a hollow steel billet as a starting point for the production of seamless hot-rolled pipes. There were no signs of shrinkage and microporosity on the hollow billet exceeding the permissible value according to the Niyama criterion.

Keywords: hollow billet, steel, modeling, pipe, 25CrMoV.

Introduction

Close conditions for the production and distribution of hydrocarbons cause a constant increase in the oil industry requirements to the pipe products properties level. This requires the intensification of work to improve the technological properties and quality indicators of continuously cast billets used for the seamless pipes production [1]. To obtain high strength characteristics of pipes, it is necessary to manufacture a high-quality continuously cast billet with minimal chemical and structural heterogeneity. Improving the quality indicators of continuously cast blanks requires technological processes optimization of continuous steel casting based on modeling.

There is a problem of continuously cast billets internal defects intended for the production of seamless oil grade pipes. Improving the production of continuously cast billets, which allows to reduce the level of pipe defects, is relevant to increase the competitiveness of domestic metal products [2,3].

The work purpose is to study the influence of the shape on the pipe billet quality and properties. At the present stage of steel production development, the continuous casting process is the most rational way to obtain blanks for the seamless pipes production. Distinctive features of a continuously cast billet are high crystallization rates and a short duration of its complete solidification. The axial zone of cast billets is the thermal center that hardens last. When solidifying a continuously cast billet in conditions of a deep, highly elongated location of the crystallizing metal well, significant convective flows are formed. These flows enhance axial segregation in a continuously cast billet and cause the formation of porosity and segregation spots in the axial zone. At the same time, an area of metal depleted by alloying impurities is often formed around the segregation spot [4,5].

As a result of the study [6], it was found that a two- or three-zone structure is formed in a continuously cast billet, depending on the extent of the two-phase state zone. For billets of large cross-sections, a three-zone structure is formed: the peripheral zone of small crystals, the zone of columnar crystallization, which has limited development, and differently oriented crystals in the axial zone.

In [7], a diagram of the continuously cast solidification process a billet. At the first stage of solidification, a relatively uniform advance of columnar crystals solidification front of occurs. At the second stage, the uniform advance of the front is disrupted. Part of the columnar crystals grows faster, and there are prerequisites for the formation of bridges in the middle uncured part of the billet. At the third stage, bridges are formed as a result of the closure of the solidification fronts. These bridges are formed when columnar crystals meet and as a result of the large crystals lowering that are “entangled” between the solidification fronts. At the fourth stage, the bridges thicken and strengthen. There are remnants of liquid metal under the bridges, which hardens similarly to metal in a conventional mill, but at a much lower speed. Micro-heterogeneity in local volumes can be almost completely eliminated as a result of heating before deformation and deformation itself. Improving the macrostructure of a continuously cast billet requires a wide zone of solid-liquid state with a solid phase predominance, where the course of shrinkage and segregation phenomena is limited.

The quality of seamless pipes is largely determined by the initial billet quality. The production process of rolled metal products includes a number of alterations, each of which contributes to the formation of the final complex of metal properties. Nevertheless, in most cases, the foundations for the formation of planned characteristics are laid primarily in steelmaking. Defects formed due to deviations from a given technology significantly reduce the technological plasticity of the metal during its further processing and operation.

A modern, relatively new technology for the production of high-quality seamless pipes is the use of initial hollow continuous cast billet. To date, there are enough known methods of forming an axial cavity in the billet. Methods of forming hollow billets directly from the melt have advantages. For example, a billet with a large cross-section entering rolling always has an increased carbon content and most impurities in the axial zone [8]. The low plasticity of the billet with a high metal impurities content in the axial zone creates a risk of ruptures during subsequent rolling. Ruptures and accumulations of impurities are stress concentrators and greatly reduce the fatigue strength of finished pipes. In this regard, the absence of the axial zone continuously cast metal billet is advisable.

It seems promising to study the formation of hollow billets directly from the melt. The advantages of a hollow billet are manifested at the stage of subsequent deformation processing. The cavity prepared during casting, made strictly axially, avoids the appearance of a large difference during subsequent piercing of the billet on a cross-screw mill [9,10].

Materials and methods

Computer simulation of forming process a hollow continuously cast billet in «LVM Flow» postprocessors has been performed. The object of the study is a pipe billet with a diameter of 210 mm made of 25CrMoV steel, the chemical composition of which is given in Table 1.

Table 1 – Continuously cast billet steel chemical composition, %

C	Si	Mn	Ni	S	P	Cr	Mo	V	Cu
0.25	0.19	0.56	0.11	0.004	0.009	1.63	0.33	0.17	0.13

The following requirements for the billet were taken into account: the macrostructure of the pipe billet should not have cracks, bubbles, crusts, foreign metal and slag inclusions and flakes. The permissible defects of the macrostructure normalized in points should not exceed the norms specified in Table 2.

For simulation processes, three-dimensional models of billet, as well as tools (crystallizer and mandrel) were created in the Compas 3D program. Next, three-dimensional models were imported into «LVM Flow». «LVM Flow» is a program for analyzing various foundry technologies, built on a modular principle and consisting of several modules, the work in which is performed sequentially. The initial and boundary conditions were set for the calculation: steel grade, material and size of the crystallizer for casting, initial temperature of the tools, melt temperature and casting speed. Alloys were selected in the materials database [11].

Table 2 – Permissible defects in the macrostructure of the pipe billet in points, no more

Steel class	center porosity	edge point contaminations	light stripes	axial segregation	segregation stripes
Alloyed	2	1	3	2	1
Unalloyed	3	2	3	3	2

When modeling in the processor module «Solidification», phase transitions and gravity were taken into account. Solidification in the program was analyzed on the basis of the thermal conductivity theory, taking into account the peculiarities of solidifying melt and shape heat transfer. The solution of the problem was based on the kinetics of the increase in the solid phase volume of the solidifying melt and the advance of the solid metal front. The ability of the crystallizer to remove heat, the thermophysical properties of the melt and the crystallizer design were taken into account. Metal seemed to be a continuous medium. To analyze the result of melt pouring and crystallization, the

Niyama criterion was used to assess the microporosity of the metal. The shrinkage of the metal was taken into account to assess the reduction in volume and linear dimensions during solidification [12].

Several factors were taken into account when modeling continuous casting of a hollow billet: casting speed, chemical composition of the alloy being poured; casting temperature; geometric dimensions of the billet section. The temperature of the casting beginning was assigned to 80–100 °C above the melting point of steel. The casting speed corresponded to that used at the operating plant of «KSP Steel» LLP. The microporosity index, the Niyama criterion, is taken as the output parameter Niy (1):

$$Niy = G/\sqrt{R} \tag{1}$$

where G, R are the temperature gradient and the cooling rate in the region under research, respectively, when the point is in a two-phase zone near the solidus temperature [13,14].

Results and discussion

All the specified input and output parameters were used in the simulation of continuous casting in «LVM Flow». The factors and their variation levels are given in Table 3.

Table 3 – The factors and their variation levels

Name of factors	– 1	0	+ 1
x_1 – casting speed, tons/min	0.271	0.273	0.275
x_2 – casting temperature, °C	1600	1655	1710
x_3 – cross-sectional area,10^{-4} m^2	333.1	339.7	346.2

For a three-factor experiment, the planning matrix will contain $N=2^3=8$ experiments according to Table 4.

Table 4 – Planning matrix

Experiment number	x_1	x_2	x_3	
1	+1	+1	+1	1.52
2	–1	+1	+1	1.65
3	+1	–1	+1	0.87
4	–1	–1	+1	1.58
5	+1	+1	–1	0.89
6	–1	+1	–1	1.64
7	+1	–1	–1	0.69
8	–1	–1	–1	0.95

Regression analysis has produced a mathematical model (2):

$$y = 1.22 - 0.23x_1 + 0.20x_2 - 0.18x_3 \tag{2}$$

After building a mathematical model, a statistical analysis was performed. Comparison of t-statistics with the tabular value Students coefficient showed that all coefficients are statistically significant and the regression equation remains unchanged. The Fischer test confirms the adequacy of the mathematical model.

Thus, the influence of changes in the casting speed, casting temperature and the cross-sectional area of the billet on the microporosity index has been confirmed. This model shows that reducing the cross-sectional area has a positive effect on improving the quality of the billet.

Then, to confirm the influence of casting geometry and technological parameters, computer simulation of the casting was carried out.

Figure 1 shows the results of modeling a hollow billet, where one feeding point was used when casting metal.

After completing the casting and solidification process, the shrinkage of the metal was analyzed (Figure 2). It can be seen that there are no shrinkage defects on the hollow billet.

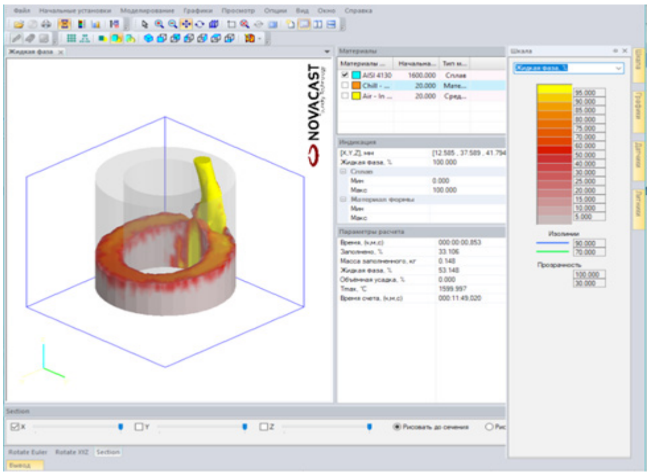

Figure 1 – Modeling of hollow billet casting

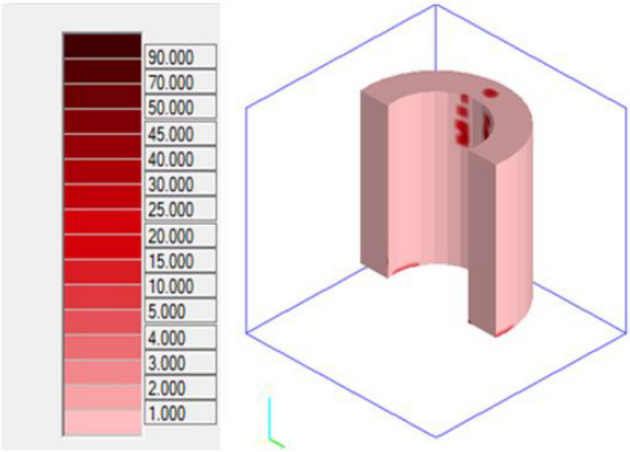

Figure 2 – Shrinkage in a hollow billet

Further, the Niyama criterion was used to determine microporosity [15]. For dense billet, values of at least 0.85 are considered the norm. The simulation results demonstrate the occurrence of shrinkage and discontinuity of the metal in Figure 3.

The use of computer simulation systems of metallurgical processes, allows you to reduce the cost of technology development. The specified modeling conditions: the casting temperature of the billet is 1600 °C and the speed is 3.6 m/min, the material of the crystallizer and mandrel when casting a hollow billet is copper. The macrostructure of the billet is evaluated according to the normative document GOST R 58228-2018 «Continuous cast steel billet. Methods of control and evaluation of macrostructure.

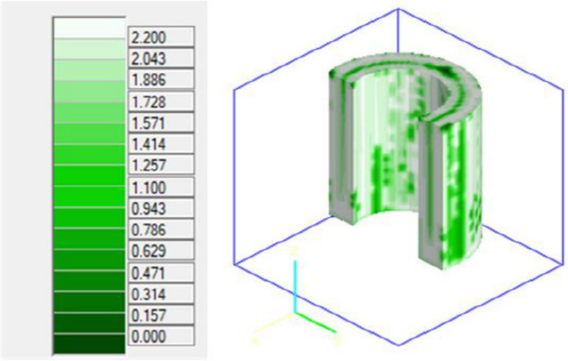

Figure 3 – Microporosity in a hollow billet according to Niyama criterion

There are significant tensile stresses in the axial zone of the billet, which lead to the destruction of its central zone when the billet meets the toe of the piercing mill mandrel. If, at the same time, the central zone of the billet is weakened by defects such as central porosity and axial segregation, then the probability of captivity formation on the inner surface of the sleeve increases. The defects are small and tightly pressed to the inner surface of the sleeve, and during subsequent calibration or reduction, such defects are opened.

Segregation strips and cracks are formed when the temperature and speed regime of casting the billet is breach. Internal cracks are fractures spreading through the interaxial spaces of the dendritic structure, enriched with liquates and accompanied by accumulations of sulfides and phosphorus segregation. Such defects will definitely lead to the destruction of the metal in the process of casting the billet. When piercing defective billets with segregation strips, coars scabs and rolled cracks are formed on the outer and inner surfaces [16]. It should also be noted that an important advantage of the hollow cast billets use in the pipes production is the rejection of hot deformation at a temperature of 1250–1280 °C. In this case, the danger of the oxides and scale formation on the product surface is eliminated, the products quality is improved and energy costs for the pipe production process are reduced.

Acknowledgements

This work was supported by the Ministry of Education and Science of the Republic of Kazakhstan within the framework of grant funding of young scientists for scientific and (or) scientific and technical projects for 2022–2024 under the IRN AP14972971 project «Research the structure formation and mechanical properties of oil assortments pipes produced from cast hollow billets».

Conclusions

To predict the structure and properties of a continuously cast billet and the product obtained from it, the process of casting a hollow billet was modeled. As a result of computer modeling in «LVM Flow», the improvement of the structure was theoretically confirmed when using a hollow steel billet as a starting point for the production of seamless hot-rolled pipes. At the same time, there are no signs of shrinkage and microporosity on the hollow billet exceeding the permissible value of more than 0.85 according to the Niyama criterion. Thus, the use of a hollow steel billet is advisable for the production of oil and gas grade pipes. The next stage of research may be to conduct a laboratory experiment on casting hollow billets, obtaining and examining pipe samples from them.

REFERENCES

1 **Zhakupova, A., Bogomolov, A., Zhakupov, A.** «The Influence of the Initial Billet on the Mechanical Properties of Pipes» IOP Conference Series: Materials Science and Engineering, vol. 969(1), article 012033, 2020. – Mentaliter 10.1088/1757-899X/969/1/012033.

2 **Choudhary, S.** «Influence of Modified Casting Practice on Steel Cleanliness» // ISIJ Int., 2011. – vol. 51(4). – P. 557–565. – https//doi.org/10.2355/isijinternational.51.557.

3 **Kobayashi, M., Isobe, K., Arai, M.** «Technical progress in steelmaking and casting for special bar and wire steel at Muroran work» // Nippon Steel Technical Report. – 2012. – vol. 394. – P. 119–124.

4 **Rogberg, B.** «Influence of Soft Reduction on the Liquid Flow Velocity and Pore Formation in the Mushy Zone» // In The 2nd ISIJ-VDEh-Jernkontoret Joint Symposium. – 2017. – P. 12–13.

5 **Smirnov, Y., Sklyar, V.** «Development of the method prevention of internal cracks in process of soft reduction contiuously cast blooms» // METAL 2010 – 19th International Conference on Metallurgy and Materials // Conference Proceedings, 2010.

6 **Dauby, P., Kunstreich, S.** «Application of micro-refrigerators as the active element on the crystallization of metal» // ISS Tech. – 2003. – P. 491–504.

7 **Nakashima, J., Kiyose, A., Ohtani, Y., Fukuda, J., Kawase, T., Doki, M.** «Micro–refrigerators» // Nippon Steel Technical Report. – 2002. – Vol. 86. – P. 68–73.

8 **Thome, R., Harste, K.** «Principles of billet soft-reduction and consequences for continuous casting» // Isij International. – 2006. – Vol. 46(12). – P. 1839–1844, https//doi.org/10.2355/isijinternational.46.1839.

9 **Zhakupov, A., Bogomolov, A., Zhakupova, A., Abdulina, S., Salina, V.** «Determination of technological parameters for continiuous casting of a hollow pipe billet», Metalurgija, 2021. – Vol. 60(3–4), P. 329–331, [Electronic resource]. – https://hrcak.srce.hr/clanak/372265.

10 **Yong, T., Hackl, G., Nitzl, G.** «Optimization of submerged entry nozzles to improve steel cleanliness and productivity» // Proceedings of 8th European Continuous Casting Conf., Graz, Austria, 2014. – P. 487–497.

11 **Shen, M., Zang, Z., Shu, K.** «Mathematics simulation and experiments of continuous casting with strip feeding in mold», Metalurgija, vol. 56(3–4), P. 315–318, 2017. – [Electronic resource]. – [Electronic resource]. – https://hrcak.srce.hr/file/266727.

12 **Popa, E., Mihu, G., Alexa, V.** «Simulation Tendencies in the Continuously Cast Half-products Area» // Acta Techical Corviniensis-Bulletin of Engineering. – 2010. Vol. 1(III). – P. 95–102.

13 **Ardelean, E., Lascutoni, A., Ardelean, M., Socalici, A., Heput, T.** «Simulation of solidification process for billet with ф350mm section, continuous casted» // IOP Conference Series: Materials Science and Engineering, 2016. – Vol. 106(1), article 012034, https//doi.org/10.1088/1757-899X/106/1/012034.

14 **Li, D., Su, Z., Chen, J., Wang, Q., Yang, Y., Nakajima, K., He, J.** «Effects of electromagnetic swirling flow in submerged entry nozzle on square billet continuous casting of steel process» // ISIJ international. – 2013. – Vol. 53(7), P. 1187–1194. – https//doi.org/10.2355/isijinternational.53.1187.

15 **Stulov, V.** «Temperature Differences in the Mold of a Continuous-Casting Machine with a New Cooling System» // Steel Transl., 2018. – Vol. 48. – P. 78–81. – https//doi.org/10.3103/S0967091218020134.

16 **Carlson, K., Beckermann, C.** «Prediction of shrinkage pore volume fraction using a dimensionless Niyama criterion», Metallurgical and Materials Transactions A. – 2009. – Vol. 40. – P. 163–175. – https//doi.org/10.1007/s11661-008-9715-y.

Accepted for publication on 07.12.23

***А. Т. Жакупова*[1], *А. Н. Жакупов*[2]**
[1,2]Торайғыров университеті, Қазақстан Республикасы, Павлодар қ.
Басып шығаруға 07.12.23 қабылданды.

МҰНАЙ ҚҰБЫРЛАРЫНЫҢ ҚҰЙЫЛҒАН ҚУЫС ДАЙЫНДАМАСЫНЫҢ ҚҰРЫЛЫМЫН МОДЕЛЬДЕУ

Жіксіз мұнай құбырларын өндіру үшін қуыс дайындамаларды құю процесін модельдеу жүргізілді. Жұмыстың мақсаты геометриялық пішіннің үздіксіз құйылган құбыр дайындамасының сапасы мен қасиеттеріне әсерін зерттеу болды. Модельдеу параметрлері, бастапқы және шекаралық шарттар агымдагы өндіріс жагдайларын ескере отырып таңдалды. Зерттеу нысаны диаметрі 210 мм құбыр дайындамасы болды. дайындамаларды құю және қатайту процесін модельдеу кезінде төмен легирленген құрылымдық хром-

молибден болаты қолданылды. Процестерді модельдеу үшін дайындамалардың үш өлшемді модельдері, сондай-ақ пішін модельдері жасалды. Қуыс дайындаманы үздіксіз құюды және кристалдануды модельдеу кезінде бірнеше факторлар ескерілді: құю жылдамдығы, құйылатын қорытпаның химиялық құрамы; құю температурасы; дайындаманың көлденең қимасының геометриялық өлшемдері. «LVM Flow» бағдарламалық кешенінде қуыс дайындамаларды құюды модельдеу дайындаманың шөгілмейтін құрылымының қалыптасуын және микрокеуектілігінің төмендеуін (Нияма критерийі бойынша 0,85-тен астам) болжады. Имитациялық модельдеу нәтижесінде қуыс болат дайындаманы жіксіз ыстықтай илемделген құбырларды өндірудің бастапқы көзі ретінде пайдалану кезінде құрылымның жақсаруы теориялық тұрғыдан расталды. Қуыс дайындамада Нияма критерийі бойынша рұқсат етілген мәннен асатын шөгу және микро кеуектілік белгілері анықталған жоқ.

Кілтті сөздер: қуыс дайындама, болат, модельдеу, құбыр, 25ХМФА.

***А. Т. Жакупова*[1], *А. Н. Жакупов*[2]**
[1,2]Торайгыров университет, Республика Казахстан, г. Павлодар.
Принято к изданию 07.12.23.

МОДЕЛИРОВАНИЕ СТРУКТУРЫ ЛИТОЙ ПОЛОЙ ЗАГОТОВКИ НЕФТЯНЫХ ТРУБ

Проведено имитационное моделирование процесса литья полых заготовок для производства бесшовных нефтяных труб. Целью работы было исследование влияния геометрической формы на качество и свойства непрерывнолитой трубной заготовки. Параметры моделирования, начальные и граничные условия были выбраны с учетом условий текущего производства. Объектом исследования являлась трубная заготовка диаметром 210 мм. При моделировании процесса литья и затвердевания заготовок использовалась низколегированная конструкционная хромомолибденовая сталь. Для моделирования процессов были созданы трехмерные модели заготовок, а также модели форм. При моделировании непрерывной разливки и кристаллизации полой заготовки учитывалось несколько факторов: скорость разливки, химический состав разливаемого сплава; температура литья; геометрические размеры сечения заготовки. Моделирование литья полых заготовок в программном комплексе «LVM Flow» спрогнозировало формирование безусадочной структуры и снижение микропористости (более 0,85 по критерию Ниямы) заготовки. В результате имитационного моделирования теоретически подтверждено улучшение структуры при использовании полой стальной заготовки в качестве исходной для производства бесшовных горячекатаных труб. На полой заготовке не выявлено признаков усадки и микропористости, превышающих допустимое значение по критерию Ниямы.

Ключевые слова: полая заготовка, сталь, моделирование, труба, 25ХМФА.

Теруге 08.12.23 ж. жіберілді. Басуға 29.12.23 ж. қол қойылды.
Электрондық баспа
5,07 Mb RAM
Шартты баспа табағы 17,26 Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: Е. Е. Калихан
Корректор: А. Р. Омарова

Тапсырыс № 4166

«Toraighyrov University» баспасынан басылып шығарылған
Торайғыров университеті
140008, Павлодар қ., Ломов көш., 64, 137 каб.

«Toraighyrov University» баспасы
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.
67-36-69

e-mail: kereku@tou.edu.kz
nitk.tou.edu.kz