https://doi.org/10.15407/scine18.03.023

GOGAEV, K. O. (https://orcid.org/0000-0002-0042-1759),
and SYDORCHUK, O. M. (https://orcid.org/0000-0003-0026-7525)
Frantsevich Institute for Problems of Materials Science, the NAS of Ukraine,
3, Krzhizhanovsky St., Kyiv, 03142, Ukraine,
+380 44 390 8751, vvk@ipms.kiev.ua

DIE STEEL WITH REGULATED AUSTENITIC TRANSFORMATION FOR HOT DEFORMATION OF COPPER-NICKEL ALLOY

Introduction. *At the operating temperature (above 650 °C), even the most heat-resistant steels (GOST 5950—2000) significantly weaken, which is the main reason for rapid failure of tools. The additional introduction of nickel alloying element into the chemical composition of ferrite-based steel makes it possible to reduce the critical points A1 and A3. Due to this, a new class of steels that belong to the ferrite state, at room temperature, and shift to the austenitic region at operating temperature has been developed.*

Problem Statement. *IThe use of die steel for hot deformation (DSHD) is limited to a certain temperature range above which it gets weaker therefore to increase the service life of such steels requires their additional alloying and the use of energy-intensive processes of their heat treatment. In alloyed structural steels of ferrite state, at a high temperature, there is reported the coagulation of carbide phases, with the heat resistance decreasing in the course of tempering.*

Purpose. *The purpose of this research is to increase the service life of the die tool (dies) made of alloy structural steel for hot pressing of copper-nickel alloy at operating temperature of 850—950 °C.*

Materials and Methods. *Metallographic studies of steel, X-ray phase analysis, dilatometric analysis.*

Results. *In the case of hot deformation of the copper-nickel alloy MNZh 5-1, the service life of the dies made of RATE 4Kh3N5M3F steel increases in comparison with 3Kh3M3F steel.*

Conclusions. *The die steels with the initial ferrite state to be used in the austenitic state are determined by the temperature position of $\alpha \rightarrow \gamma$ — transformation. The tool warmup during the operation ensures such a transformation during the next long operation in the austenitic state. That is, within the entire period of high-temperature operation of the tool, the austenitic structure of the steel is preserved. This method differs from the conventional approach to heat-resistant alloy die steels for which, on the contrary, an increase in the phase transformation temperature is one of the main conditions for enhancing the durability of tools for hot deformation.*

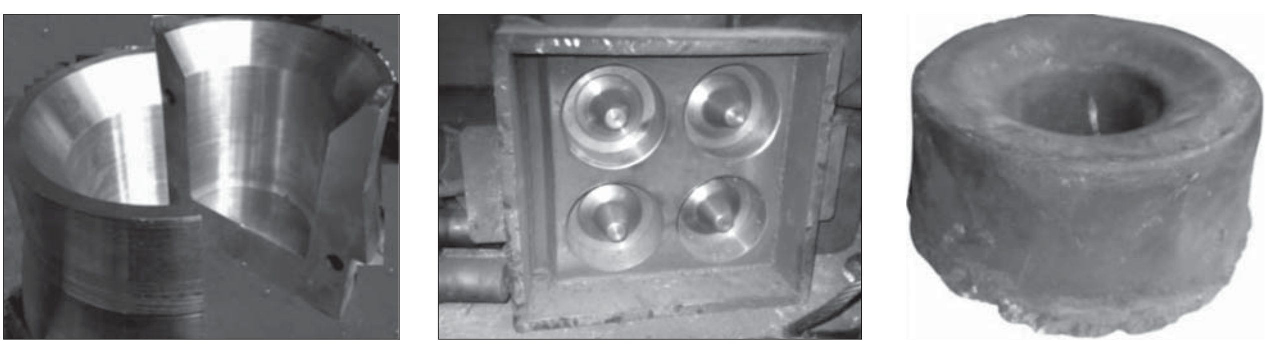
Keywords: steel, copper-nickel alloy, austenitic transformation, chemical composition, heat treatment, temperature, mechanical properties, structure, and punching tool.

Citation: Gogaev, K. O., and Sydorchuk, O. M. (2022). Die Steel with Regulated Austenitic Transformation for Hot Deformation of Copper-Nickel Alloy. *Sci. innov.*, 18(3), 23—27. https://doi.org/10.15407/scine18.03.023

While producing 4Kh3N5M3F steel, to obtain the required chemical composition, usually manufacturers introduce Fe — Ni — Mo — V — Mn [1] system ligature made at the Frantsevich Institute of Problems of Materials Science of the NAS of Ukraine into the scrap of 3Kh3M3F base steel. The ligature is obtained in an induction furnace, with the liquid metal poured into a mold (Fig. 1, *a*). The temperature of the metal in the furnace before release is 1550 °C. The duration of refining does not exceed 20 min. The ingots are obtained by electroslag remelting in the mold (Fig. 1, *b*, *c*) and undergo incomplete annealing at a temperature of 750 ± 20 °C. The steel chemical composition corresponds to 4Kh3N5M3F grade (% wt.): 0.40—0.44 C; 2.80—3.00 Cr; 4.70—5.50 Ni; 2.44—2.60 Mo; 1.34—1.36 V; 0.34—0.35 Si; 0.25—0.28 Mn; 0.004—0.005 S; and 0.003—0.004 P. The steel is sampled according to GOST 7565—81. The steel chemical composition is determined by spectral analysis [2, 3]. The carbon content in the steel is measured with the use of analyzers AN 7560M and AN 7529M.

It should be noted that the manufacture of matrices does not involve energy-intensive technological processes (forging and annealing), unlike in the case of technology presented in [4]. The main achievement of studies [5—7] is having made the annealing (partial recrystallization) of steel, which involves the heat treatment technology that is more optimal and less energy-intensive as compared with that suggested in [4]. In the studies, it has been shown that for pre-eutectoid alloy steel 4Kh3N5M3F, in the case of partial recrystallization, there is formed a spheroidizing carbide component of pearlitic-sorbide structure, which contributes to the improvement of machining workpieces for the manufacture of matrices. The steel hardness after heat treatment is determined by the Rockwell method on TC-2 device (GOST 9013-73) and amounts to 32HRC. The steel microstructure is studied with the use of an optical microscope MIM-10. There have been studied steel sections after etching with a 5% solution of nitric acid in ethyl alcohol with the addition of picric acid, according to the method described in [8]. The X-ray phase analysis is made with the use of a DRON-3 diffractometer in Co-Kα radiation. To establish the critical points A_1 and A_3 of steel, dilatometric analysis has been made by method [9].

PJSC Artemivsk Plant for Machining of Nonferrous Metals (Bakhmut, Ukraine) has been using matrices made of 3Kh3M3F steel (GOST 5950-2000) for punching tools. This steel is used for the manufacture of matrices for hot deformation on eccentric presses and horizontal forging machines. As a rule, small tools made of this steel are subjected to intensive cooling in the course of operation. It is also used to make injection molds for copper alloys. For the long-term processes of hot pressing (at an operating temperature of 850—950 °C) of ingots made of MNZh5-1 copper-nickel alloy and production of pipes, dies of steels



a *b* *c*

Fig. 1. 4Kh3N5M3Ф Steel: collapsible chill mold for obtaining ingots of Fe — Ni — Mo — V — Mn ligatures (*a*) system; mold for obtaining four ingots by electroslag remelting (*b*); ingot (weight 15 kg) (*c*)

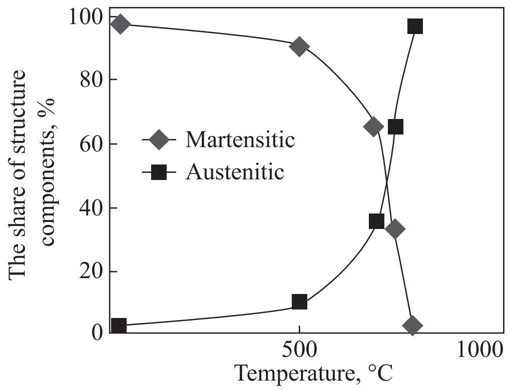


Fig. 2. Change in the share of austenitic and martensitic components depending on the temperature of hardened steel 4Kh3N5M3F [10]

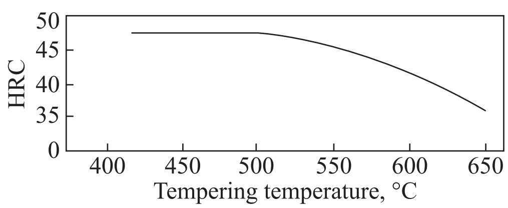
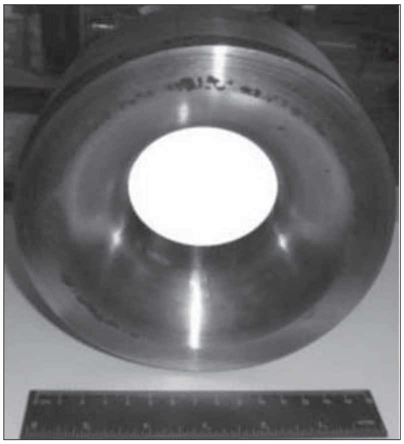


Fig. 3. Dependence of the hardness of cast blanks made of 4Kh3N5M3F die steel obtained by electroslag remelting, hardened at 1030 ± 10 °C on tempering temperature

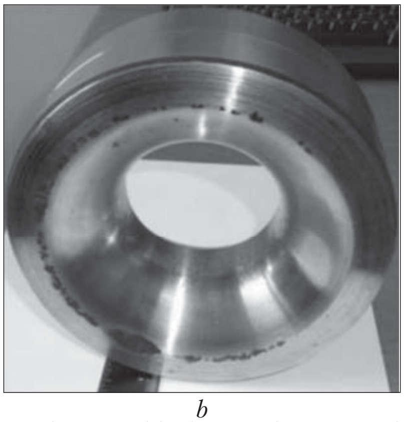
with regulated austenitic transformation during exploitation (RATE steels) 4Kh3N5M3F steel are used. The deformation of MNZh 5-1 alloy at a heating temperature above 700 °C (critical point A_1) and below 850 °C (critical point A_3) is not desirable, as in this temperature range, there is the recrystallization process, as it has been shown in the course of studying the relationship between the phase structural state (α — Fe and γ — Fe) of 4Kh3N5M3F steel and the Vickers hardness (GPa) [10, 11].

The dependence of the share of austenite on the heating temperature within the temperature range from 20 to 800 °C is nonlinear and close to exponential one (Fig. 2) [10]. As the temperature increases, the share of austenitic component grows. This has allowed us to confirm that during the operation of the press tool at a temperature above 850 °C, the austenitic structure is preserved. As a result of the analysis it has been found that as the temperature increases, the amount of ferrite phase decreases, while that of austenite goes up. At a temperature of 800 °C, the share of austenite is 97%. The high-temperature X-ray phase analysis has confirmed the correctness of determining the critical points A_1 = 700 °C and A_3 = 850 °C for 4H3N5M3F steel, which were previously determined by dilatometric analysis [5, 6, and 10]. Studies [11, 12] have shown that the tempering temperature of steel (1030 ± 10 °C) given the tempering at a temperature of 580 ± 5 °C (air cooling) is sufficient, as the heat resistance of steel is 44HRC (Fig. 3). Above 620 °C, the steel gets weaker as its hardness is below 40HRC (at a room temperature), Fig. 3.

Thus, thanks to the optimized heat treatment conditions, the cast steel may be used for the



a



b

Fig. 4. Die made of cast blanks of 4Kh3N5M3F die steel, after hot deformation of copper-nickel alloy MNZh 5-1 (PJSC Artemivsk Plant for Machining of Nonferrous Metals, Bakhmut, Ukraine), dimensions: *a* — diameter; *b* — thickness

manufacture of punching tools for hot pressing of nonferrous metals and alloys.

At PJSC Artemivsk Plant for Machining of Nonferrous Metals (Bakhmut, Ukraine) there have been tested dies (Fig. 4, *a*, *b*) of cast 4Kh3N5M3F steel for the manufacture of pipes with a diameter of Ø 67 ± 0.1 mm, made of MNZh 5-1copper-nickel alloy at a deformation temperature of 850—950 °C. An ingot with a diameter of 220 mm, a length of 370 mm, and a weight of 120 kg is used as a blank. In order to ensure the operation within the temperature range 850—950 °C, with the tool working in the austenitic region, it is necessary to preheat the die to 350 °C, and while operating, its working part heats up above 850 °C. Totally, 7 dies have been used. Up to 20-ton copper alloy has been pressed on each of them. The comparative analysis of the dies for hot deformation of MNZh 5-1 copper-nickel alloy in the manufacture of pipes has shown that the use of cast 4Kh3N-5M3F steel increases three times the service life as compared with forged 3Kh3M3F steel. In addition, the overall durability of the die made of RATE steel increases 5—6 times in the case of its further use for a larger pipe diameter, by re-drilling and heat treatment (hardening and tempering) of the die.

The research has been funded from 1) the target complex program of the NAS of Ukraine *Problems of Duration of Service Life and Safety of Structures, Facilities, and Machines,* from 2013 to 2015, *Development of Technology for the Production of Cast Die Steel for Hot Deformation with Regulation of Austenitic Transformation No. R.7.19*; 2) grant support from the Government Fund for Fundamental Research under the competitive project № F73/24 and the Belarus Republican Fund for Fundamental Research, agreement with BRFFD № T16K-009, from 2016 to 2017, *Development of R&D Framework for the Manufacture of Molding Tools Based on the Creation and Use of New Promising Steels and Foundry-Deformation Methods for Their Machining.*

REFERENCES

1. *Sydorchuk, O. M., Mamonova, A. A., Luk'yanchuk, V. V., Gogaev, K. O., Radchenko, O. K., Myroniuk, L. A., Konoval, V. P., Shvedova, H. L., Myroniuk, D. V.* (2020). Cast steel with regulated austenitic transformation during operation, obtained by electroslag remelting. *Successes of materials science,* 1, 77—85 [in Ukrainian].
2. Babushkin, A. A., Bazhurin, P. A., Korol'ov, F. A. (1962). *Methods of spectral analysis* Moscow. Production of Moscow University. 509 p. [in Russian].
3. Petrov, V. I. (1973). *Optical and X-ray spectral analysis* . Moscow. 285 p. [in Russian].
4. Nguyen, S. Kh. (2021). Structure and hardening of steel with regulated austenitic transformation during exploitation (Doctoral dissertation). Proquest Dissirtation and Theses. Moskow [in Russian].
5. Sydorchuk, O. M. (2013). Phase-structural state of steel 40Kh3N5M3F in the process of recrystallization. *Modern problems of physical materials science. Proceedings of the Institute of Problems of Materials Science im. I. N. Frantsevich NAS of Ukraine. Series «Physico-chemical bases of powder materials technology»*, 22, 186—188 [in Ukrainian].
6. Gogaev, K. O., Sydorchuk, O. M., Radchenko, O. K., Mamonova, A. A. (2014). Die steel for hot deformation with regulated austenitic transformation. *Metal Science of Treatment of Metals*, 1, 40—44 [in Ukrainian].
7. *Patent of Ukraine № 94746*. Gogaev K. O., Sydorchuk O. M., Radchenko O. K., Luk'yanchuk V. V. The method of heat treatment of steel for hot pressing [in Ukrainian].
8. Panchenko, E. V., Skakov, Yu. A., Krymer, V. I., Arsent'ev, P. P., Popov, K. V., Tsviling, M. Ya. (1965). *Metallography laboratory*. Moscow. 440 p. [in Russian].
9. Shurin, A. K. (1964). Differential high-sensitivity dilatometer with heating in an inert medium. *Questions of physics of metals and metallurgy*, 18, 222-225 [in Russian].
10. Gogaev, K. O., Sydorchuk, O. M., Radchenko, O. K., Karpets', M. V., Pyatachuk, S. G. (2015). Structure and properties of hardened steel 40Kh3N5M3F, obtained by electroslag remelting at high temperatures. *Metallofizika i noveishie tekhnologii*, 12(37), 1653—1661 [in Ukrainian].
11. Gogaev, K. O., Radchenko, O. K., Sydorchuk, O. M., Luk'yanchuk, V. V. (2015). Technology of production of die steel 40Kh3N5M3F for hot deformation. *Target comprehensive program of the National Academy of Sciences of Ukraine «Problems of resource and safety of operation of structures, structures and machines» Institute of electric welding. Ye. O. Paton of the National Academy of Sciences of Ukraine*, 669—672 [in Ukrainian].

12. Gogaev, K. O., Sydorchuk, O. M., Radchenko, O. K., Luk'yanchuk, V. V., Orel, H. H. (2016). Research of modes of heat treatment of die steel 4Kh3N5M3F. *Modern problems of physical materials science. Proceedings of the Institute of Problems of Materials Science im. I. N. Frantsevich NAS of Ukraine. Series «Physico-chemical bases of powder materials technology»*, 25, 105—108 [in Ukrainian].

Received 18.10.2021
Revised 03.12.2021
Accepted 03.12.2021

К.О. Гогаєв (https://orcid.org/0000-0002-0042-1759),
О.М. Сидорчук (https://orcid.org/0000-0003-0026-7525)
Інститут проблем матеріалознавства імені І. М. Францевича НАН України,
вул. Кржижановського, 3, Київ, 03142, Україна,
+380 44 390 8751, vvk@ipms.kiev.ua

ШТАМПОВА СТАЛЬ З РЕГУЛЮВАННЯМ
АУСТЕНІТНОГО ПЕРЕТВОРЕННЯ ДЛЯ ГАРЯЧОГО
ДЕФОРМУВАННЯ МІДНО-НІКЕЛЕВОГО СПЛАВУ

Вступ. При експлуатаційних температурах (понад 650 °C) навіть найбільш теплостійкі сталі (ГОСТ 5950-2000) інтенсивно знеміцнюються, що є основною причиною швидкого виходу інструменту з ладу. Додаткове введення легуючого елемента нікелю в хімічний склад сталі на феритній основі дало можливість знизити критичні точки A_1 і A_3. Завдяки чому, було розроблено новий клас сталей, які за кімнатної температури належали до феритного стану, а за експлуатаційної — перетворювались в аустенітну область.

Проблематика. Використання штампової сталі для гарячого деформування (ШСГД) обмежене певним температурним інтервалом, вище якого відбувається їхнє знеміцнення і для підвищення ресурсу експлуатації яких необхідним є додаткове легування та використання енергоємних процесів їх термічної обробки. У легованих конструкційних сталях феритного стану при високих температурах відбувається коагуляція карбідних фаз і знижується теплостійкість в процесі відпуску.

Мета. Підвищення ресурсу експлуатації штампового інструменту (матриць) з легованої конструкційної сталі для гарячого пресування мідно-нікелевого сплаву за робочих температур 850—950 °C.

Матеріали й методи. Металографічні дослідження сталі, *X*-променевий фазовий аналіз, дилатометричний аналіз.

Результати. При гарячому деформуванні мідно-нікелевого сплаву МНЖ 5-1 було підвищено ресурс експлуатації матриць зі сталі з регульованим аустенітним перетворенням 4Х3Н5М3Ф порівняно зі сталлю 3Х3М3Ф.

Висновки. Штампові сталі з вихідною феритною основою для роботи в аустенітному стані визначаються положенням температур $\alpha \rightarrow \gamma$-перетворення. Розігрів інструменту в процесі експлуатації повинен забезпечити проходження такого перетворення для подальшої тривалої роботі сталі в аустенітному стані, тобто протягом всього періоду високотемпературної експлуатації інструменту зберігається аустенітна структура сталі. У цьому полягає відмінність від традиційного підходу до легованих теплостійких штампових сталей для яких, навпаки, підвищення температур фазових перетворень є одним з основних умов підвищення стійкості інструменту для гарячого деформування.

Ключові слова: сталь, мідно-нікелевий сплав, аустенітне перетворення, хімічний склад, термічна обробка, температура, механічні властивості, структура, штамповий інструмент.