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TECHNICAL STATE ANALYSIS OF REACTION ROD BRACKETS STEEL CASTINGS FOR BUSES

Lesya Svirska[1]; Denys Bartoshevskyi[1, 2]; Sofiia Krechkovska[2]; Andrian Ugryn[3]; Ivan Kurnat[1]; Lidiia Bohyn[2]

[1]Karpenko Physico-Mechanical Institute of the NAS of Ukraine, Lviv, Ukraine
[2]Lviv Polytechnic National University, Lviv, Ukraine
[3]Ukrainian National Forestry University, Lviv, Ukraine

Summary. *The technical state of the unexploited steels brackets' metal has been analyzed. Their mechanical properties inconsistency with the regulated requirements has been revealed. It has been shown that the elongation δ of the bracket metal, which varied from 1.8 to 3.3%, and the yield strength were lower than the regulated level. The low values of δ and obtained ratios of yield strength to ultimate tensile strength (σ_{YS} / σ_{UTS}) indicate a low ductility reserve of the bracket metal, consequently posing a high risk of unforeseen brittle fracture during operation.*

Key words: *steel castings, bracket, strength, ductility, fracture.*

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Statement of the problem. Foundry production is important for engineering because its simplicity, low energy consumption, and manufacturing cost have made it possible to produce a significant portion of large, complex geometry parts for machines and equipment [1, 2]. Already in the foundry production stage, metal in its molten state is poured into molds whose dimensions correspond to the parameters of the required parts, and after its cooling and crystallization, practically finished products are obtained. The main processes of foundry production include metal melting, mold making, metal pouring and cooling, extraction of blanks from molds, cleaning and trimming of excess casting residue, heat treatment, and quality control of castings.

During the production of cast parts, some defects occur. According to technical requirements, if a casting has at least one unacceptable defect, it is considered defective. Defects can be determined by inconsistency of microstructure, chemical composition, physical, and mechanical properties. Defects are divided into four groups: I – geometry inconsistency (due to incomplete filling of forms with molten metal, inconsistency of wall thickness of hollow castings, distortion), II – surface defects (burning, growths that disrupt the geometry of the part), III – cavities in the body of the casting (shrinkage cavities during crystallization, gas cavities, pores of various origins), IV – various types of inclusions [3–4]. Defects in castings are caused by various reasons, including substandard molding materials, poor quality charge for melting metal, inappropriate design of the part (its complex nature is not technologically suitable for casting), or the organization of the casting process itself with poorly thought-out casting technology, low-quality molds, weak technological control, and others [5–9].

The aim of the work is to analyze the technical condition of the metal of two brackets on the basis of the determining their chemical composition and mechanical characteristics through tensile and impact testing.

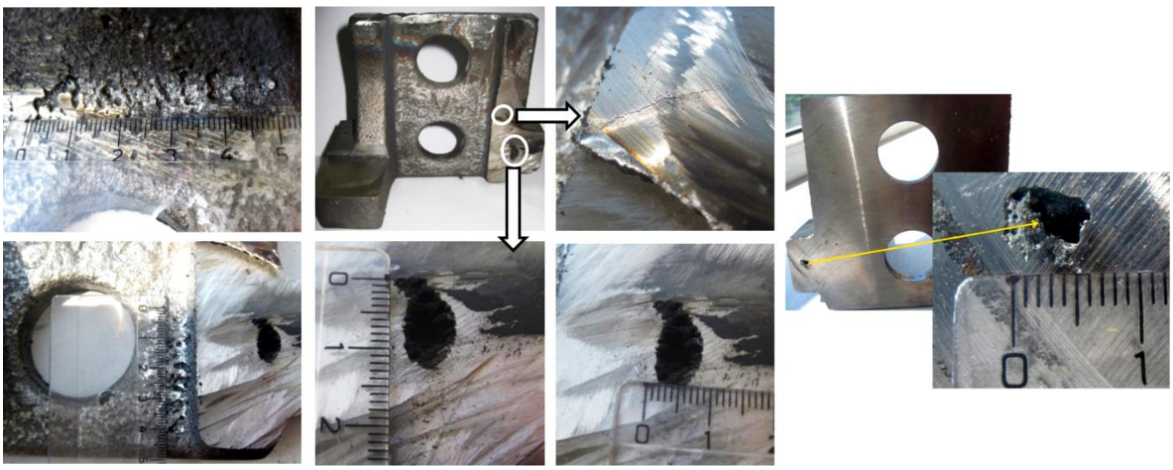
Corresponding author: Lesya Svirska; e-mail: lesyasvirska@gmail.com

Object and methods of the research. The castings of two brackets for the reactive rod were investigated in the unexploited state. The content of alloying elements in the metal of the brackets (mass, %) was evaluated using an optically spark atom-emission spectrometer SPECTROMAX LMF 0.5. For this purpose, flat specimens with a cross-section of 20×20 mm were prepared, the thickness of which was reduced by grinding on both sides to 3…5 mm.

Impact testing was carried out on beam specimens (10×10 mm in cross-section) with a sharp stress concentrator of the Sharpy type (with a V-shaped notch, the radius at the apex of which is 0.02 mm) with a depth of 2 mm. The specimens were tested on a pendulum impact tester type IO – 5003.

The mechanical properties of the casting metal, namely strength characteristics (yield strength σ_{YS} and ultimate tensile strength σ_{UTS}) and ductility (elongation δ and reduction of area ψ), were determined based on the results of tensile testing of standard smooth cylindrical specimens (diameter 5 mm and five times the length of the working section). To eliminate grinding marks, which could serve as stress concentrators during tensile testing, and thus increase data scatter, the working portion of the specimens was polished before testing using abrasive paper and diamond pastes of various grit sizes. The specimens were tested on a universal testing machine UME-10T at a deformation rate of $3{\cdot}10^{-3}$ s^{-1}.

Results and their discussion. First of all, we have analyzed the unexploited brackets of the reactive rods to identify any damages. By visual inspection of their surface, we noted several specific features (see Figure 1). In particular, we found defects in the castings in the form of small and larger blisters, associated with unsatisfactory surface cleanliness (see Figure 1a). Deep shrinkage cavities were observed in the body of the brackets, which had an irregular oval shape. The size of the largest one reached 13×8 mm (see Figure 1 b). One of these shrinkage cavities was found on the external surface of the bracket casting (see Figure 1 c).



a *b* *c*

Figure 1. General view of the casting surface of the bracket (a) with an internal cavity and a crack in its cross section (b) and with a deep cavity in casting exposed to surface (c)

Using the dye penetrant method on the surface of one of the brackets, cracks of lengths 5 and 9 mm were also identified. During the operation of the bracket, which would be subjected to a cantilever bending scheme, these cracks would be located in a plane perpendicular to the direction of the applied forces (see Figure 2). Moreover, the maximum forces would occur precisely in the area of structural stress concentrators, that is, in the cross-section of the analyzed elements, where these long cracks were found.

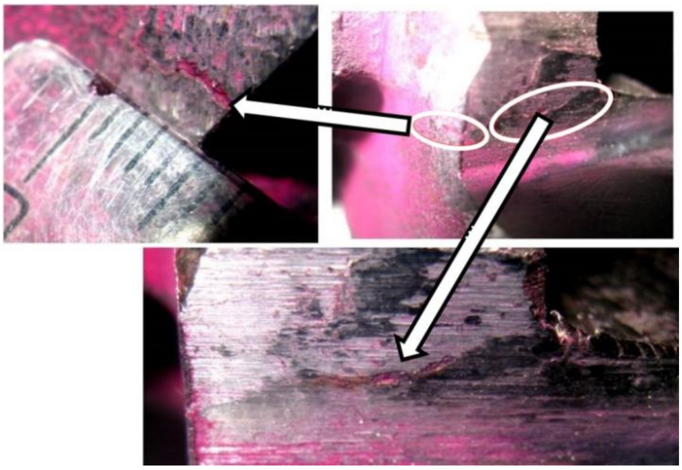


Figure 2. Cracks on the outer surface of the bracket

The average content of alloying elements in the bracket metal based on three measurements is presented in Table 1. The analysis of the obtained data has showed that according to DSTU 8781:2018, in terms of the content of basic elements, bracket steel № 1 mostly corresponds to the chemical composition of steel 30L, while bracket № 2 corresponds to steel 50L, but due to the 0.5 mass % Cr content, it is more likely to be classified as steel 50KhHL. Nevertheless, slightly elevated Mn content was noted in bracket metal № 1 (1.13 mass % compared to the maximum allowable content of 0.9 mass %). Moreover, in the composition of steel 50KhHL, approximately 0.34 mass % Cu and approximately 0.11 mass % Ni were found, which are not provided for by the mentioned regulatory document. In the composition of steel 30L from bracket № 2, Cr, Cu, Ni, and also high S and P content were found, which are not provided for by the mentioned regulatory document and are not favourable factors for its mechanical characteristics, as they contribute to its brittleness.

Table 1

Chemical composition of the bracket metal, wt. %

	C	Mn	Si	Cr	S	P	Cu	Ni
Bracket №1	0,5	1,13	0,50	0,6	0,04	0,03	0,34	0,11
Steel 50KhHL (DSTU 8781:2018)	0,45–0,60	0,5–0,9	0,2–0,5	0,6–0,9	0,04	0,04	-	-
Bracket №2	0,31	0,90	0,49	0,28	0,07	0,05	0,09	0,13
Steel 30L (DSTU 8781:2018)	0,27–0,35	0,45–0,9	0,2–0,52	-	0,04	0,04	-	-

Impact toughness is considered a fundamental characteristic for determining the technical condition of metal. It is used as an indicator of resistance to brittle fracture. So, impact toughness was utilized to assess the sensitivity of metal to the influence of notches and defects under high deformation rates. It was found that the impact toughness of bracket metal №1 and № 2 was 100 and 70 KJ/m2, respectively (see table 2). Taking into consideration that the analyzed elements are responsible for safe bus operation, and then they should have sufficient resistance to brittle fracture accordingly. The obtained values are lower (at least 2.5 times) than those regulated for such types of steels (since the KCV values are not regulated for steel 50KhHL, the requirements for steel 50L were taken as a prototype). However, with the use of appropriate heat treatment regimes, this difference may be even greater (see table 2).

Based on the obtained results, it can be concluded that the ability of the metal to resist brittle fracture is insufficient, therefore, the brackets made of the analyzed metal cannot be used in operation.

Table 2

Impact toughness of brackets metal, KCV, MJ/m^2 (KJ/m^2)

Bracket №1	0,1 (100)
Bracket №2	0,07 (70)
50KhHL (DSTU 8781:2018)	Not less than 0,245 (245)

The mechanical properties of the metal of both brackets were also analyzed, and it was found that their ultimate tensile strength (σ_{UTS}) ranged from 615 to 824 MPa, while the yield strength (σ_{YS}) ranged from 492 to 531 MPa. Moreover, the ratio σ_{YS} / σ_{UTS}, which is commonly used to characterize the ability of steel to plastically deform until reaching its strength level, was 0.77 for the bracket metal №1 and 0.62 and 0.86 for the bracket metal № 2. According to the established notions regarding this plasticity reserve ratio σ_{YS}/σ_{UTS}, often used in the energy sector, exceeding its level beyond 0.7 poses a risk of brittle fracture. The data provided in the standard correspond to a high level of plasticity reserve in steels, thus indicating a low probability of brittle fracture. However, in our case, this ratio in two out of three tested samples significantly exceeded this value, which is indicative of a precarious state of the metal in terms of its brittleness and the risk of premature failure of the analyzed elements. The analysis of the metal of both brackets based on ultimate tensile strength showed that regardless of which steel (50KhHL or 50L) is taken as a prototype for comparison, only one out of three samples met the requirements of DSTU 8781:2018. Although the values obtained for yield strength in all samples complied with regulatory requirements.

Table 3

Mechanical characteristics of bracket steel

	σ_{UTS}, МПа	σ_{YS}, МПа	σ_{YS}/σ_{UTS}	δ, %	φ, %
Bracket 1	633	492	0,77	2,3	1,2
Bracket 2	824	511	0,62	3,3	5,9
	615	531	0,86	1,8	1,3
Steel 50KhHL, according to DSTU 8781:2018 the values not lower than					
After normalization with tempering	687	-	-	5	-
After quenching and tempering	775	-	-	13	-
Steel 50L, according to DSTU 8781:2018 the values not lower than					
After normalization with tempering	569	334	0,58	11	20
After quenching and tempering	736	392	0,53	14	

The elongation δ of the metal brackets varied from 1.8 to 3.3%, while the relative narrowing ψ ranged from 1.2 to 5.9% (see table 3). However, according to the requirements for both steel analogs regulated by DSTU 8781:2018, the lowest value of δ is achieved after normalization with tempering (for steel 50KhHL it is 5%, and for 50L – 11%), and the value of ψ for steel 50KhHL is not regulated, while for steel 50L, it should not be lower than 20%. In our case, both plasticity characteristics of the metal of the brackets under consideration have been significantly lower (at least 2–3 times) than the regulated values. Such a violation of the requirements for total deformations (by both plasticity characteristics), which precede the ultimate fracture of elements, combined with the low ability of the metal to plastically deform until reaching the maximum stress level (judging by the ratio σ_{YS} / σ_{UTS}), poses a threat of brittle unpredictable fracture of the analyzed elements even in the absence of cracks in the elements before their operation.

Conclusions. It has been determined that the prototype steel for bracket No.1 is steel 50KhHL or 50L, and for bracket No.2 it is steel 30L. A slight deviation in the content of alloying elements from the regulated levels for these steels has been noted. The resistance to brittle fracture of the metal in both brackets was found to be low, particularly for steel 50L, where the KCV value was almost 2.5 times lower than the regulated level. It has been established that despite the compliance with the regulated values of the yield strength of the metal in both brackets, their ultimate tensile strength values do not meet this requirement. Regarding the ductility characteristics, they are 2...3 times lower than permissible.

Non-compliance with the requirements regarding the magnitude of total deformation (for both ductility characteristics) preceding the final failure of the elements has also been identified. Considering the low ability of the metal to plastically deform until reaching the maximum stress level (in terms of the σ_{YS} / σ_{UTS} ratio), brittle and unpredictable failure of the analyzed elements becomes possible even in the absence of cracks in the elements before their operation.

The performed certification of metal for such critical components for automotive transport as bracket castings has justified the necessity of mandatory incoming inspection of the castings according to the following algorithm: visual inspection of their surface for compliance of detected defects with quality requirements for castings; random inspection for the presence of internal defects and their compliance with requirements; determination of the chemical composition of castings from one batch and their mechanical properties as a basis for ensuring their operability providing there aren’t any unacceptable external and internal defects in the castings.

References

1. Development of mechanical engineering in Ukraine: problems and ways to solve them: monograph, State University “Institute of Regional Studies named after M. I. Dolishnyi National Academy of Sciences of Ukraine”; Science editor, Doctor of Economics Science, Prof. S. O. Ishchuk. Lviv, 2022, 137 p.
2. Ocheri C. The role of foundries in spare parts production and economics development of nigeria using ajaokuta steel company as a case study. International Journal of Innovative Studies in Sciences and Engineering Technology. 2020, 6 (7), pp. 38–44.
3. Popovych V., Popovych V. Technology of structural materials and materials science: textbook for students. Technical special higher education closing. Lviv, Svit, 2006. 624 p.
4. Types of casting defects. Electronic edition – Mode of access: https://studfile.net/preview/10102566/page:2/.
5. Stoian E. V., Bratu V., Enescu C. M, Rusanescu C. O. Analysis of internal defects appeared in the continuous casting. Scientific Bulletin of Valahia University. Materials and Mechanics, 16 (14), pp. 23–27 https://doi.org/10.1515/bsmm-2018-0005
6. Blair M., Monroe R., Beckermann C., Hardin R., Carlson K., Monroe C. Predicting the occurrence and effects of defects in castings. The J. Minerals. Metals and Materials Society, 2005, 57, p. 29–34. https://doi.org/10.1007/s11837-005-0092-3
7. Kalandyk B., Głownia J. Wady wtórnego zazuzlenia na przemysłowych odlewach ze staliwa, Archiwum Odlewnictwa, 2007, 6 (22), pp. 254–259.
8. Kalandyk B., Zapała R., Rakowska A. Characteristics of defects present in industrial steel castings due to metal-mould reactions. Archives of metallurgy and materials, 2009, 54 (2), pp. 289–297.
9. Achamyeleh A. Kassie, Samuel B. Assfaw. Minimization of casting defects. IOSR Journal of Engineering, 2013, 3 (5), pp. 31–38. https://doi.org/10.9790/3021-03513138

Список використаних джерел

1. Розвиток машинобудування в Україні: проблеми та шляхи їх вирішення: монографія, ДУ «Інститут регіональних досліджень імені М. І. Долішнього НАН України» / наук. редактор д.е.н., проф. С. О Іщук. Львів. 2022. С. 137.

2. Ocheri C. The role of foundries in spare parts production and economics development of nigeria using ajaokuta steel company as a case study. International Journal of Innovative Studies in Sciences and Engineering Technology. 2020. 6 (7). P. 38–44.
3. Попович В., Попович В. Технологія конструкційних матеріалів і матеріалознавство: підручник для студ. техн. спец. вищ. навч. закл. Львів : Світ, 2006. 624 с.
4. Види дефектів при литті. Електронне видання. URL: https://studfile.net/preview/10102566/page:2/.
5. Stoian E. V., Bratu V., Enescu C. M, Rusanescu C. O. Analysis of internal defects appeared in the continuous casting. Scientific Bulletin of Valahia University. Materials and Mechanics 16 (14). P. 23–27 https://doi.org/10.1515/bsmm-2018-0005
6. Blair M., Monroe R., Beckermann C., Hardin R., Carlson K., Monroe C. Predicting the occurrence and effects of defects in castings. The J. Minerals, Metals and Materials Society. 2005. 57. P. 29–34. https://doi.org/10.1007/s11837-005-0092-3
7. Kalandyk B., Głownia J. Wady wtórnego zazuzlenia na przemysłowych odlewach ze staliwa, Archiwum Odlewnictwa 2007. 6 (22). P. 254–259.
8. Kalandyk B., Zapała R., Rakowska A. Characteristics of defects present in industrial steel castings due to metal-mould reactions. Archives of metallurgy and materials. 2009. 54 (2). P. 289–297.
9. Achamyeleh A. Kassie, Samuel B. Assfaw. Minimization of casting defects. IOSR Journal of Engineering. 2013. 3 (5). P. 31–38. https://doi.org/10.9790/3021-03513138

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АНАЛІЗ ТЕХНІЧНОГО СТАНУ СТАЛЕВИХ ВИЛИВОК КРОНШТЕЙНІВ РЕАКТИВНОЇ ШТАНГИ ДЛЯ АВТОБУСІВ

Леся Свірська[1]; Денис Бартошевський[1,2]; Софія Кречковська[2]; Андріан Угрин[3]; Іван Курнат[1]; Лідія Богун[2]

[1]Фізико-механічний інститут імені Г. В. Карпенка НАН України, Львів, Україна
[2]Lviv Polytechnic National University, Львів, Україна
[3]Національний лісотехнічний університет України, Львів, Україна

Резюме. *Проаналізовано технічний стан металу неексплуатованих кронштейнів, виявлено невідповідність їх механічних властивостей регламентованим вимогам. Встановлено, що за вмістом основних елементів сталь кронштейна № 1 відповідає хімічному складу сталі 30Л, а кронштейна № 2 – сталі 50Л, але через вміст 0,5 мас. % Cr її слід віднести до сталі 50ХГЛ. Показано, що відносне видовження δ металу кронштейнів, яке змінювалося від 1.8 до 3,3%, та границя міцності були нижчими регламентованого рівня. Згідно з вимогами для обох сталей-аналогів, регламентованими ДСТУ 8781:2018, найнижче значення δ досягається після нормалізації з відпуском (для сталі 50ХГЛ воно становить 5%, а для 50Л – 11%), а значення ψ для сталі 50ХГЛ не регламентуєть, а для сталі 50Л – має бути не нижчим за 20%. Низькі значення δ та співвідношень між границями плинності та міцності σ_{YS} / σ_{UTS}, свідчать про низький запас пластичності металу кронштейнів і відповідно високу ймовірність їх непрогнозованого крихкого руйнування під час експлуатації. Враховуючи те, що аналізовані елементи відповідальні за безпечне керування автобусом, то повинні мати високий опір крихкому руйнуванню. Встановлено, що ударна в'язкість металу кронштейнерів № 1 та № 2 становила 100 та 70 KJ/m^2 відповідно. Отримані значення є нижчими (у 2,5 раза) за регламентовані для такого типу сталей (оскільки для сталі 50ХГЛ значення KCV не регламентовані, то за прототип взяли вимоги до сталі 50Л). Проведено атестацію металу виливків кронштейнів для автомобільного транспорту. Рекомендовано необхідність обов'язкового вхідного контролю литва, що включає візуальний контроль їх поверхні щодо відповідності виявлених дефектів вимогам до якості виливок, вибірковий контроль на наявність внутрішніх дефектів і їх відповідність вимоги, а також визначення хімічного складу виливок однієї плавки та їх механічних властивостей як основа для забезпечення їх роботоздатності.*

Ключові слова: *сталеві виливки, кронштейн, міцність, пластичність, руйнування.*

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