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Overhead Cranes Undercarriage Steel Wheels' Operational Destruction Analysis

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Abstract. *The features of crane wheels operation are considered on the basis of a brief review of information sources. On the fact of the breakdown, there was studied the nature and causes of the destruction of a double-flange crane wheel made of 65G steel. The research methodology included hardness measurement, fractographic analysis by the type of fractures, and microstructural analysis of the material. As a result of studying the destroyed wheel of the undercarriage of an overhead crane, cold cracks were found by the type of fracture. The analysis of the microstructure of the metal of the rim and flange of the wheel showed a predominantly bainite structure with coarse inclusions along the grain boundaries. The surface structure is represented by intermediate structures of the sorbitol + bainite type with inclusions of products of incomplete decomposition and tempering of martensite. According to the results of the study, the manufacturer was recommended to change the existing heat treatment technology: volumetric quenching in oil followed by tempering. Taking into account the peculiarities of the operation of this type of parts, sorbitization is recommended for them in special sets of the horizontal or vertical type. The use of such air cooling units provides the lamellar sorbitol structure. This technology, due to uniform cooling of the wheel, significantly reduces residual stresses and increases the service life.*

Keywords: *wheel, steel, sorbitol, bainite, microstructure, heat treatment, destruction.*

Introduction

Verge wheels of overhead cranes are one of the most loaded and critical parts of lifting and transport equipment.

Double-flange crane wheels are used for almost any type of crane. They adhere very tightly to the rails and prevent the crane from derailing. However, the increased friction of the wheels against the rails increases the resistance during crane movement and the wear of the verge wheel and the rail itself. Therefore, used two-flange crane wheels are made of high-strength steel.

The operating conditions of the crane wheels are highly stressed. Axle loads lead to increase the dynamic effect on the wheels, and increase in contact stresses and in the intensity of wheel rim wear. It has been established that the main cause of wheel turns is the wear of the rolling surface. For this defect, over 50% of the wheels are turned.

Weld joints are used to provide stronger guide rail connections and continuous contact with the wheel, which can cause greater localized plastic deformation and therefore lead to a higher sensitivity to crack propagation. As a rule, it is crack resistance that is the dominant damage mode in cases where hardened wheel steel is used under heavy loads. The great concern is that this type of damage can be a network of micro cracks, what can propagate to deeper depths than those usually found in verge wheels and, therefore, are more difficult to remove by grinding during repairs [1].

Residual stresses of steel wheels' structural elements can contribute to the development of transverse defects and increase the risk of wheel failure at an early stage, combined with a higher dynamic load, which usually occurs during crossing the weld joints of crane runways [2].

The mechanical reaction of steel materials at the wheel-rail interface mainly depends on the cyclic rolling contact conditions and material characteristics such as yield strength and hardening characteristics. If cyclic rolling contact conditions result in stress levels above the yield point, the new plastic deformation will be generated and accumulated in each loading cycle. The increment in plastic deformation per cycle can be small, but it can accumulate to large values over many cycles during operation. When the deformation reaches the yield point of the material, first of all the destruction of the wheel begins at a local material point, at the seat of the future crack development. The specific pressure at the junction reaches 500 MPa [2].

Thus, it should be noted that a complex loading of crane wheels occurs during operation. Taking into account the responsibility of these parts, the main requirement for the material manufacture is to ensure the necessary fatigue strength [3].

Research and methodology

The requirements for the efficiency of crane wheels are most satisfied by carbon and spring steels. Specific operating conditions, design features and the

purpose of the wheel determine the choice of material and technology of hardening processing finally.

As a rule, medium-carbon, low-alloy steels of grades 45 and 55C2 and in some cases steel 65G are used for the manufacture of crane wheels after heat treatment. The technology for the production of crane wheels has its own differences depending on the purpose, conditions of the manufacturer and other factors.

The classical version of the technology for manufacturing steel crane wheels provides the pressure treatment, heat treatment and mechanical treatment. Heat treatment of the wheel provides the quenching and tempering to relieve residual stresses in the temperature range 400-600°C. The heating temperature for hardening is determined by the chemical composition of the steel, and for tempering; according to research [4], a heating temperature is recommended in the range of 480-520°C, then holding for 2 hours with air cooling. The type of used equipment for heat treatment is also essential for obtaining high-quality wheels. In the conditions of large-scale production, the use of quenching and tempering units can be considered optimal, providing complex thermal or chemical-thermal treatment of this type products.

The research methodology included hardness measurement, fractographic analysis of fractures type, and microstructural analysis of the material. Material grade data was obtained from the manufacturer's certificate. The determination of hardness was carried out by the Brinell method according to the current method of State Standard 9012-59 (ISO 410-82, ISO 6506-81), the measurement was carried out with a portable hardness tester of the TEMP type.

Fractographic analysis at this stage of the study was carried out visually due to the significant dimensions of the destroyed part. Microstructure analysis was carried out using an Olympus BX53 optical microscope according to the standard procedure 5639-82.

Obtained results and their discussion

On the fact of a fracture, a study of the metal structure was carried out at one of the local enterprises to identify the nature and causes of brittle destruction of a double-flange crane wheel operated on an overhead crane (Figure 1a).

It should be noted that the sudden fragile destruction of such critical part as a verge wheel during the operation of an overhead crane is a very rare but it is dangerous production situation.

An external examination of the part revealed two cracks located on opposite sides of the wheel tangentially to the rim. One of the cracks is open, the second one propagates into the body of the part up to the hole. The appearance of the fracture is shown in Figure 1b. The fracture surface is clean, unoxidized, no obvious internal material defects were found. The nature of the fracture is fragile. By the nature of the fracture and the location of the cracks, it was determined that the detected cracks are stress cracks (cold cracks).

The surface hardness of the destroyed wheel was 370 HB. The part is a 65G steel forging. The detected cracks appeared after heat treatment. The cause of the destruction and the quality of the part material were investigated additionally, after carrying out microstructural analysis in laboratory conditions. On the remaining wheels, it is recommended to carry out additional non-destructive crack control; prepared templates for microstructural analysis are shown in Figure 2.

Figure 3 shows the microstructure of the wheel

a) b)

a – general view, b – break

Figure 1 – Crane wheel after destruction

material along the flange. Analysis of the microstructure of the rim metal and flange of the wheel showed a predominantly bainitic and martensitic structure with coarse inclusions along the grain boundaries.

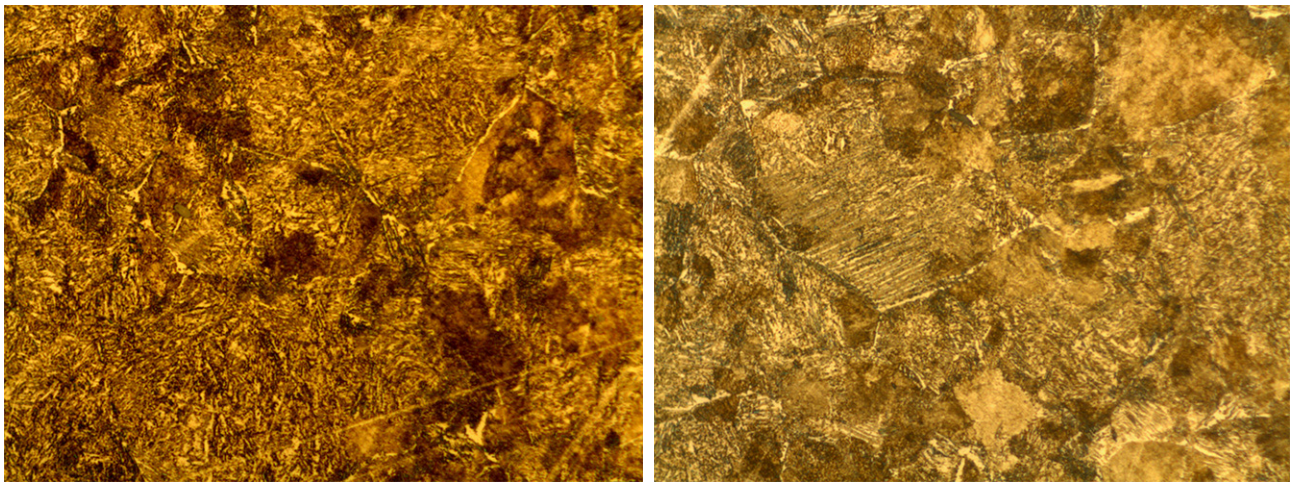
Figure 3b shows grain boundaries and the structure of predominantly upper bainite and tempered martensite, maintaining the orientation of the martensite needles. This allows us to conclude that the heat treatment was incorrectly assigned, since in the production of steel wheels for the running gear of mechanisms, it is recommended to provide the structure of sorbitol [5].

Figure 4 shows the microstructure of the wheel rim surface as the fracture crack propagated from the rim contact surface to the transport hole. The surface structure is represented by intermediate structures of the sorbitol + bainite type with inclusions of incomplete decomposition products and tempering of martensite.

Figure 4b shows clearly the types of cracks propagating along the grain boundaries, which caused the destruction of the steel wheel.

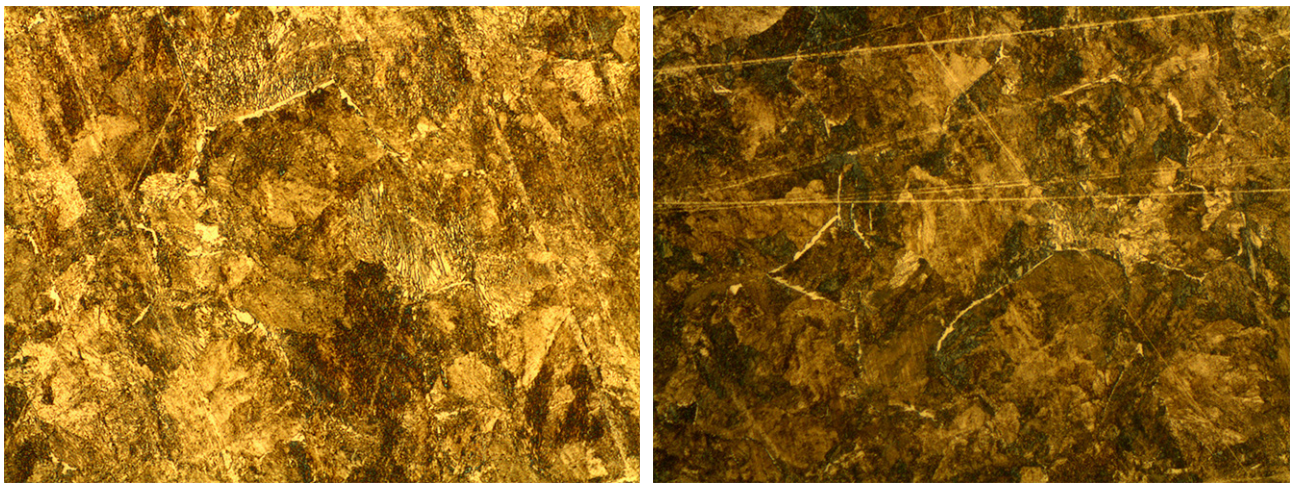
According to preliminary data, the manufacturer of crane wheels uses heat treatment – volumetric

Picture 2 – Prepared templates, steel 65G, etching, nital



a) b)

Figure 3 – Microstructure of the wheel material along the flange, steel 65G, x1000: a) at a depth of 2 mm from the surface, b) at a depth15 mm from the surface



a) b)

Figure 4 – Microstructure of the wheel rim surface, steel 65G, a) x1000, b) x500 – destruction of the surface along the boundaries of large grains

oil quenching followed by tempering. Moreover, manufacturers in the conditions of small-scale production use conventional quenching tanks. Although, given the operation peculiarities of this part type, sorbitization is recommended for them in special installations of a horizontal or vertical type. Verge wheels of overhead cranes have a complex profile of the working surface. Therefore, for uniform cooling and ensuring a homogeneous structure, it is necessary to carry out increased heat extraction from the rolling surface. Earlier, based on the results of research, a number of methods for strengthening steel wheels and design options for the corresponding installation of a vertical type were developed.

According to these innovative solutions, wheels are subjected mainly to two types of final heat treatment: normalization with tempering or quenching. Heating is carried out up to 800-860°C, depending the actual composition of the steel, followed by controlled cooling. Cooling should ensure the production of lamellar sorbitol in all elements of the wheel.

Conclusion

As a result of fractographic and microstructural analysis of the destroyed crane wheel material, it was concluded that the heat treatment mode was incorrectly assigned for this part during its manufacture at the enterprise.

For large traveling crane wheels, it is recommended to harden the rim by spraying water or a water-air mixture simultaneously over the entire rolling surface of the wheel, rotating it in a horizontal plane. In this case, by controlling the temperature, composition and flow rate of the cooling medium, it is possible to achieve the required hardness values at a given distance from the rolling surface. For prompt adjustment of the sorbitization technological process, it is also recommended to control the wheel rotation speed additionally.

It is recommended to adjust the existing technology of crane wheels heat treatment of to ensure the required level of quality in the production of these critical products, improve service and operational characteristics with a minimum level of additional production costs.

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Көпірлі крандардың жүріс бөлігінің болат доңғалақтарының эксплуатациялық бұзылуын талдау

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Аңдатпа. *Ақпарат көздеріне қысқаша шолу жасау негізінде кран дөңгелектерін пайдалану ерекшеліктері қарастырылады. Сыну фактісі бойынша 65 г болаттан жасалған қос қабырғалы кран доңғалағының бұзылу сипаты мен себептерін зерттеу жүргізілді. Зерттеу әдіснамасына қаттылықты өлшеу, сынықтардың түріне фрактографиялық талдау, материалды микроқұрылымдық талдау кірді. Көпірлі кранның шассиінің бұзылған дөңгелегін зерттеу нәтижесінде сынық түрінде суық жарықтар табылды. Металл микроқұрылымын талдау доңғалақтың құрсауы мен қабырғасы дән шекаралары бойынша өрескел қосындылары бар негізінен бейнит құрылымын көрсетті. Беттік құрылым-бұл сорбит+бейн түріндегі толық емес ыдырау және мартенситті босату өнімдері қосылған аралық құрылымдар. Зерттеу нәтижелері бойынша өндірушіге термиялық өңдеудің қолданыстағы технологиясын өзгерту ұсынылады – кейіннен босата отырып, майда көлемді шынығу. Бөлшектердің осы түрін пайдалану ерекшеліктерін ескере отырып, олар үшін көлденең немесе тік типтегі арнайы қондырғыларда сорбиттеу ұсынылады. Мұндай қондырғыларды ауада салқындату үшін пайдалану пластина сорбитінің құрылымын қамтамасыз етеді. Бұл технология дөңгелектің біркелкі салқындауына байланысты қалдық кернеуді едәуір төмендетеді және пайдалану мерзімін арттырады.*

Кілт сөздер: *дөңгелек, болат, сорбит, бейнит, микроқұрылым, термиялық өңдеу, бұзылу.*

Анализ эксплуатационного разрушения стальных колес ходовой части мостовых кранов

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Аннотация. *Рассмотрены особенности эксплуатации крановых колес на основе краткого обзора информационных источников. По факту поломки проведено исследование характера и причин разрушения двухребордного ходового кранового колеса из стали 65Г. Методология исследования включала измерение твердости, фрактографический анализ по виду изломов, микроструктурный анализ материала. В результате исследования разрушенного колеса ходовой части мостового крана по виду излома обнаружены холодные трещины. Анализ микроструктуры металла обода и реборды колеса показал преимущественно бейнитную структуру с грубыми включениями по границам зерен. Структура поверхности представляет собой промежуточные структуры типа сорбит+бейнит с включениями продуктов неполного распада и отпуска мартенсита. По результатам исследования предприятию-изготовителю рекомендовано изменить существующую технологию термической обработки – объемную закалку в масле с последующим отпуском. Учитывая особенности эксплуатации данного вида деталей, для них рекомендуется сорбитизация на специальных установках горизонтального или вертикального типа. Использование таких установок для охлаждения на воздухе обеспечивает структуру пластинчатого сорбита. Такая технология, благодаря равномерному охлаждению колеса, существенно снижает остаточные напряжения и увеличивает эксплуатационный ресурс.*

Ключевые слова: *колесо, сталь, сорбит, бейнит, микроструктура, термическая обработка, разрушение.*

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