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ISSN 0543-5846
METABK 59(1) 121-124 (2020)
UDC – UDK 621-59: 621-772: 621.72: 620.178.3: 620. 16=111

USE OF REINFORCING ELEMENTS TO IMPROVE FATIGUE STRENGTH OF STEEL STRUCTURES OF MINE HOISTING MACHINES (MHM)

Received – Primljeno: 2019-07-10
Accepted – Prihvaćeno: 2019-09-07
Preliminary Note – Prethodno priopcenje

The article discusses the issues of fatigue fracture of steel structures and the method of increasing their strength through the use of reinforcing elements. The authors set the search for ways to improve steel structures and to reduce their metal intensity without reducing strength and increasing their resistance to fatigue failure, except for the use of expensive high-strength alloys. They have proposed a method for strengthening the structure and searching for its optimal shape of the loaded part, capable with a smaller wall thickness to withstand fatigue failure of steel structures of mine hoisting machines used to transport metallurgical coke in long-term operation. The results of computer modeling the stress-strain state of a steel beam under operating loads are given.

Key words: brake, reinforcing elements, fatigue strength, fatigue crack modeling, mechanical stresses.

INTRODUCTION

Mine hoisting machines (MHM) of the ArcelorMittal Company have been in operation for more than 30 years, and the problem of the fatigue destruction of their structures is acute. The volume of transportation of metallurgical coke from the mine to the surface increases annually. Reliability and safety of operation of the hoisting machines as a whole largely depend on the technical condition of steel structures. Using the methods of ultrasonic flaw detection, the authors carried out a survey of 57 MHMs of the ArcelorMittal Company. As a result of examining the brake devices, the following defects have been revealed: 38,5 % are wear and damage of hinge joints and 57,3 % are fatigue cracks in steel structures (beams, hauls, drums).

The authors have analyzed the problem of fatigue fracture of structures [1-3] and have studied the causes and factors that affect the mechanism of fatigue fracture in steels [4-8].

They have developed their own trend of solving the problem of fatigue failure of the MHM brake device structure based on computer simulation methods, ultrasonic flaw detection and magnetic metal memory [9]. They use the ANSYS program that allows simulating the stress-strain state of the MHM elements and replacing the cumbersome full-scale tests of experimental samples. By modeling, it is possible to find the optimal variant to strengthen the structure for increasing its strength and reliability parameters. They have developed practical recommendations for restoration of durability by carrying out repair and restoration work using structural reinforcing elements. According to the results of the studies, practical recommendations have been developed for repairing and reinforcing the design of brake beams for the ArcelorMittal MHMs of the 2 TS – 4 x 2,3; 2 C – 5 x 2,3; 2 C – 5 x 2,4 and 2 C – 6 x 2,4 types. The method has been used by engineers of the

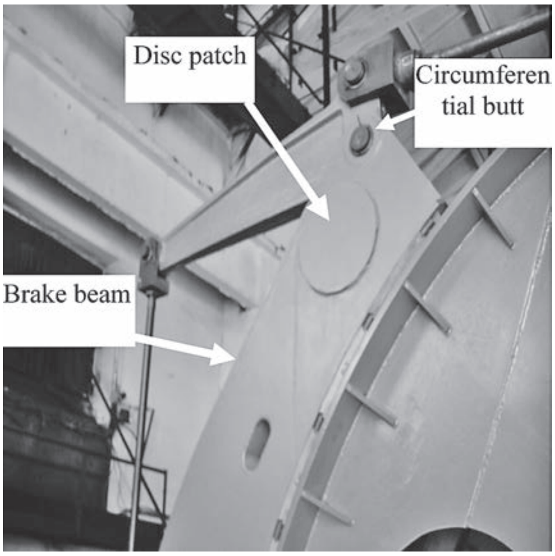

Figure 1 Practical use of structural reinforcing elements in the repair of the ArcelorMittal MHM design

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ArcelorMittal Company in repairing metal structures of the MHM mechanical part after the fatigue failure of the brake beam. An example of mounting a reinforcing element on the MHM is shown in Figure 1.

As further practical observations have shown after mounting the reinforcing element, the possibility of the fatigue cracks growth and destruction of the steel structure is completely excluded.

COMPUTER MODELING OF THE STRESS-STRAIN STATE OF A STEEL STRUCTURE

The authors have developed an adequate computer model for studying the stress-strain state of the steel structure of the MHM brake mechanism. They are establishing the location of emergency-hazardous zones of concentration of mechanical stresses, leading to the formation of fatigue cracks. It is necessary to search for solutions to strengthen the structure in the place of its fatigue fracture and to reduce the risk of cracking. A computer model has been developed taking into account all the technical parameters of the real steel beam of the brake mechanism. Mechanical stress concentrators have been identified that lead to the development of fatigue cracks in the σ_{max} region and reduce the durability under cyclic loads, respectively. The “emergency-hazardous deformation zones” are formed in the beam structure.

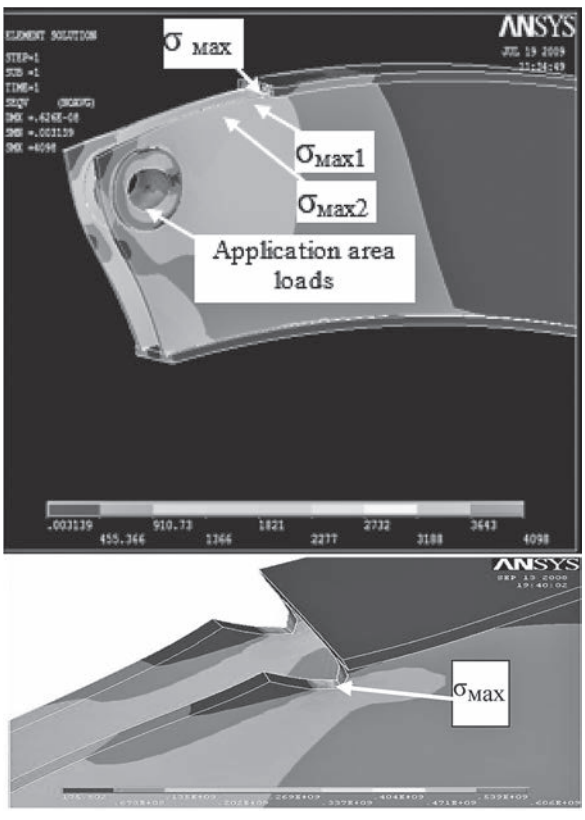

Figure 2 Computer model of the beam design with zones σ_{max}, σ_{max1}, σ_{max2} that are stress concentrators leading to the development of fatigue cracks and the process of development is cracked

Figure 2 shows a graphic representation of the pattern of mechanical stresses distribution and crack opening in the σ_{max} zone modeled in the ANSYS program.

The arrows indicate the zones with the highest concentration of mechanical stresses; during the operation of the beam fatigue cracks are formed. The use of patch elements allows excluding the possibility of further fatigue fracture associated with repeated cyclic application of loads to the brake elements during its operation. The patch reinforcing elements can be a disc patch, a rib, a ring patch, or their combined variants. The patch elements are mounted on the side faces of the beam using a welded or adhesive bond. The manufacturing technology and mounting patch elements is simple and does not require the use of complex welding and assembling equipment. Figure 3 shows the proposed options for structural reinforcements that are able to influence the nature of cracks development, significantly reducing the stress concentration, and thus increasing strength and structural reliability.

The authors have developed 44 computer models of the beam and carried out their testing with various options of reinforcing elements combinations, as well as their location on the beam body. Based on the scientific analysis, one of the most effective reinforcing options is presented in Figure 3.

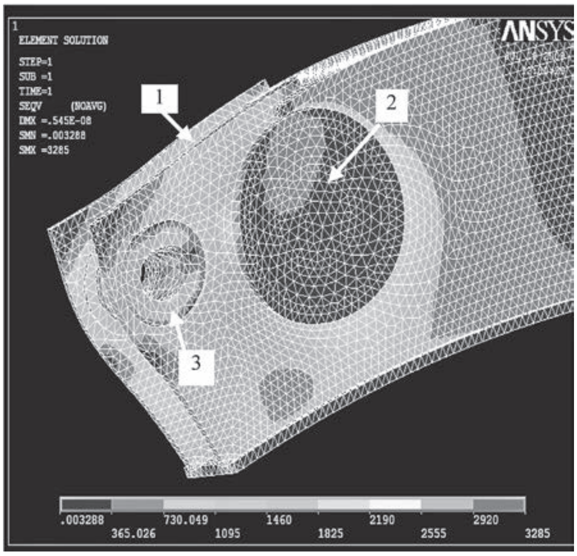

Figure 3 Computer model of the beam design with structural reinforcing elements: 1 - “rib”, 2 - “disc patch”, 3 - “ring patch”

This option is the most appropriate one for this situation. The reinforced construction of a beam with the wall thickness of 20 mm is able to withstand the same load as a beam with the wall thickness of 40 mm, since only the loaded part is strengthened, and the thickness of the unloaded part can be reduced to 2 times. The reinforcing elements are made of the same steel grade as the beam, in our case it is CT10 low carbon structural steel (Russia), its American equivalent is AISI C1010 or German DIN C 10. The capabilities of the ANSYS program allow simulating the load on beam elements associated with cyclical load and cycle asymmetry. Simulation allows setting the exact geometric dimensions of the reinforcing elements and their location on the body of the beam. In the process of modeling, it has been possible to establish the nature of changing the growth rate of a fatigue crack that depends on the asymmetry coefficient of the stress intensity cycle. The use of structural reinforcing elements makes it possible to reduce the range of the stress-intensity cycle asymmetry factor and to reduce significantly the pre-positioning of the crack closure to changing the state at the fatigue threshold and the stress-cycle asymmetry, which ultimately reduces the probability of fatigue crack growth.

Figure 4 shows some results of studying the stress-strain state of imitation computer models of beams. Among the 44 beams, the best option with the best fatigue fracture strength indicators has been selected. The graph proves the possibility of reinforced structure 3 with the wall thickness of 20 mm working equally reliably under operational loads, as well as structure 2 with the wall thickness of 40 mm, which is not achievable for structure 1 (Figure 4). The experimental data have been approximated using a computer program with a regressive estimate.

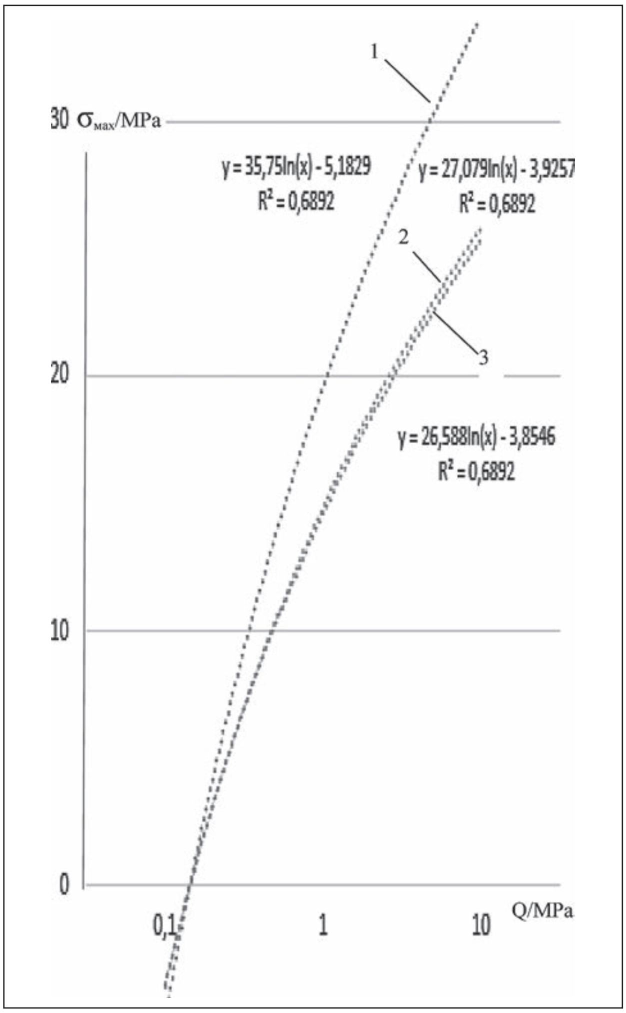

Figure 4 Dependences of maximum stresses σ_{max} on the operational load Q for various models: 1 - simulation computer model, with the wall thickness of 20 mm; 2 - simulation computer model, with the wall thickness of 40 mm; 3 - simulation computer model with the wall thickness of 20 mm and reinforcing elements

In the graph in Figure 4 it can be seen that using a combination of elements such as “disc patch”, “ring patch” and “rib” allows increasing structural strength to fatigue failure. Decreasing the mechanical stress values in the zone $\sigma_{мах}$ of the steel structure of the beam is observed. Similar dependences are noted.

The practical positive results of using reinforcing elements of the brake beam device obtained during repair are confirmed by the results of simulation modeling using the ANSYS program. Simulation allows you to set the exact geometric dimensions of the gain elements and their location on the body of the beam. In the process of modeling, it was possible to establish the nature of the change in the growth rate of the fatigue crack, which depends on the stress-intensity cycle asymmetry factor.

RESULTS OF THE STUDY, THEIR DISCUSSION AND CONCLUSIONS

The comparative analysis of the measurement results of the stress-strain state of the beam structure and the results obtained by computer simulation are shown in Figure 5 and the values of mechanical stresses (MPa) in the three fatigue fracture zones $\sigma_{мах}$, $\sigma_{мах1}$ и $\sigma_{мах2}$ are indicated. Measuring mechanical stresses has been performed on a standard design of a brake beam of the mine hoist NKMZ 2TS – 4 x 2.3 with the wall thickness of 20 mm using the IKN-1m device. Figures 1 - 4 designate the beams that have been subjected to load testing equivalent to actual operating loads (MPa): 1 - a simulation computer model with the wall thickness of 20 mm; 2 - an imitation computer model with the wall thickness of 20 mm on which the reinforcing element “Disc patch” is mounted; 3 – a standard real structure of

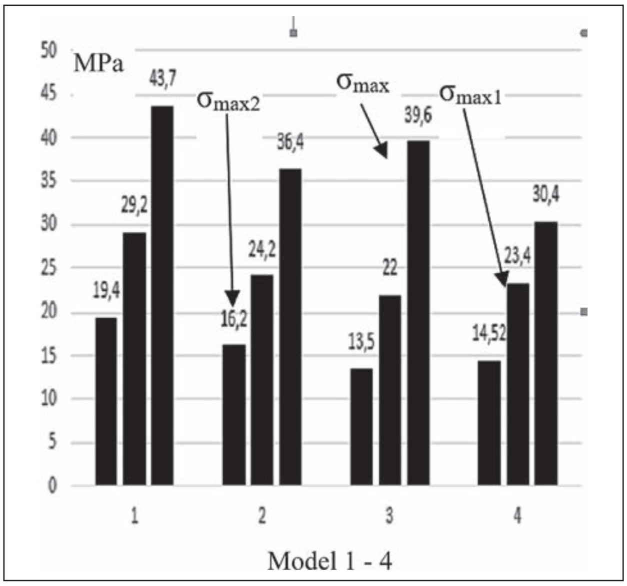

Figure 5 Results of measuring the stress–strain state of the beam structure and computer simulation

a brake beam with the wall thickness of 20 mm; 4 – a standard real structure of a brake beam with the wall thickness of 20 mm, on which the reinforcing element “Disc patch” is mounted.

Analyzing the research results, the authors can conclude that the use of reinforcing elements makes it possible to reduce the values of mechanical stresses in the zones of fatigue failure $\sigma_{мах}$, $\sigma_{мах1}$, $\sigma_{мах2}$ and to increase the structural strength. The difference in the results obtained using computer simulation and when measuring with the IKN-1m device is 12 % for beams 1 and 3 and 13 % for beams 2 and 4, respectively.

The use of reinforcing elements makes it possible to solve the problem of fatigue failure, to reduce the metal consumption of the structure and to increase fatigue failure resistance of steel structures of the brake mechanism beams of the MHM. The reinforcing elements allow restoring the steel structure strength after repair. For each steel structure of the mechanical part of the brake, it is necessary to carry out its own research complex taking into account operating loads and to develop its own models based on practical measurements using the IKN-1m device based on the metal magnetic memory. The proposed method has passed practical approbation during repair and strengthening the design of the brake beams of the ArcelorMittal Company MHMs of the 2 TS – 4 x 2,3; 2 C – 5 x 2,3; 2 C – 5 x 2,4 and 2 C – 6 x 2,4 types. The observations made using the methods of ultrasonic flaw detection within 5 years after repair show the absence of zones with fatigue cracks. The reinforcing elements can be used to increase the fatigue strength of any steel structure.

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Note: Translated from Russian into English by Tatyana B. Rumyantseva, translator of National Research Tomsk State University