Modeling of mechanical properties of dissimilar joints using the FEM approach

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Abstract. Modeling of connections in CAD class systems enables conducting simulation tests of entire structures. It gives the opportunity to reduce costs and speeds up the design process itself. Programs using the finite element method (FEM) are the oldest (over 40 years of history) and the most popular tools for modeling objects and physical processes. It is an absolutely necessary component of the knowledge of every modern engineer. In contrast to physical modeling (see below), in which quite approximate models are used, the MES program can model structures in great detail. But the calculation time for this reason can be relatively long. However the advantage of using CAE systems is the ability to understand the behavior of the object in real conditions, to conduct a numerical experiment under the influence of: load, vibration, temperature, etc. with the use of computer calculations and simulations. The paper presents the use of an advanced CAD / CAE class system for modeling complex technological joints of mechanized mining supports manufactured using the welding technology. One of the most important problems in manufacturing and repairing of mining support using the welding technology is the method of welding the dissimilar joints and analysis of its characteristics. It is particular important for the repairing procedures. A case of such approach is presented in the present paper.

1. Introduction

The mining mechanized support is a technical means that ensure stability and durability of the mining wall. Hence the purpose of using a mining support is to protect the working place against falling rocks from the roof and walls. Moreover a mining support is responsible for safe and trouble-free operation in the wall, for transport of hard coal and even ventilation. This is why the support should be adapted to the mining and geological conditions prevailing in the surroundings of the mining operation, particularly adapted to the size, purpose and life-cycle of the mining process. To obtain these objectives the mining support should be durable and easy to make and replace, especially in the mining wall [1-3]. To other objectives one should include corrosion resistance. These objectives guarantee the safe operation of this device [4-6].

The mining mechanized support consists of some important parts that ensure its continuous operation (figure 1). The main parts of the support are: canopy, hydraulic cylinders (props), lemniscate mechanism, caving shield and two foot pieces. The most exposed to overloading places are fixings of hydraulic cylinders, as through these places is transferred the force of supporting the roof in the area of
mining [7]. Moreover the load of a support is related with the stratification of beds [8,9]. This is why it is important to properly manufacture these points of the mining support construction.

Figure 1. Model of a mechanized mining support.

The analysis of mounting points of support props have been conducted using the virtual model of the V-type support elaborated in the CAD/CAM design environment [10-12]. It was analyzed the problem of stress concentration in the mounting points of support props.

2. Dissimilar welds technology

One of modern steels used in many constructions working in corrosion environment are ferritic-austenitic steels. They are becoming increasingly important in various industries also due to their higher mechanical properties and corrosion resistance compared to other corrosion-resistant steels. Plastically processed products made of duplex steel are subjected to welding processes using various techniques. Depending on the used welding method and the selection of technologies and additional materials, joints with the required properties can be obtained. Many tests have been devoted to welding of duplex steel, thanks to which welding guidelines have been developed however obtaining correct joints is associated with strict adherence to technological regimes [13-15].

The welding of duplex steel with other steels has been given less attention, although in many designs such joints are necessary [16,17]. Considering welded joints of duplex steel with other steels, the most common connection is made with carbon steel steels or with austenitic corrosion resistant steels. In the case of duplex steel - carbon steel joints, the mechanical properties, in particular the plasticity measured by impact tests or in the technological bending test are of decisive importance. Welded joints of duplex steel with austenitic steels should, in addition to good mechanical properties, have good corrosion resistance as well [18,19].

The welding problems of austenitic steels are most often associated with the appearance of hot cracks. Intercritical cracks may form during solidification and crystallization of the joint, while a large stiffening of the joint favors hot cracks in the HAZ area. The formation of hot cracks is favored by the high coefficient of linear expansion and the low thermal conductivity of austenitic steels. The tendency of hot cracking in the joints of austenitic steels can be reduced by the selection of a weld material ensuring a specific share of the delta ferrite in the weld. Welding of high alloyed austenitic steels requires the use of nickel based alloys. In this case, the crystallization of purely austenitic welds is inevitable. The reduction of the tendency to hot cracking is obtained by reducing the restraint of joints and the use of low linear welding energies, which involves the need for multi-well welding. Another problem of welding austenitic steels may be too much delta ferrite in the weld structure and
the tendency to turn ferrite into the sigma phase. This transformation, occurring in the temperature range of 600-900°C, leads to a decrease in joint ductility and deterioration of corrosion resistance characteristics [20-22].

In duplex steel joints, hot cracks are less common. This is due to a smaller coefficient of linear expansion and higher thermal conductivity compared to austenitic steel. On the other hand, fixed duplexes are very sensitive to structural changes occurring under the influence of the welding thermal cycle. Most welding problems in these steels are associated with the area of HAZ, not welds. The mechanical properties and corrosion resistance of duplex steel joints are determined by: the proportion of ferrite and austenite in the structure, morphology and size of ferrite and austenite grains, type, morphology and distribution of intermetallic phases that can be separated from ferrite. The structure of the weld and HAZ depends on the selection of additional materials for welding and the cooling speed of the joint. Too high cooling rate gives high ferrite content in the HAZ and leads to the release of nitrides, consequently causing a reduction in the plasticity and corrosion resistance of the joint. In turn, too low cooling speed, resulting from the use of high linear welding energies, can lead to the separation of harmful intermetallic phases [23,24].

3. Analyzed roof support construction
The analysis of the support construction has been done by simulation its behavior taking into consideration its operation program [25-29].

A typical mechanized roof support consists of some basic components that are in a specific way loaded in its operation process. The load is acting from the roof mass side, as it was shown in figure 2. Through the mounting points it is transferred by the props on the foot pieces. In this process the most loaded points are the mounts of props and lemniscate connectors, what is presented below. This is why it is important to manufacture these handle properly. Secondly, the load is multiplied in the situation, when the load is skew. This is due to an attempt to adjust the direction of props operation to more often skew line of roof rocks load. This situation results in more complex system of stresses, loading the mounting points.

![Figure 2. Load and stresses in main points of the support construction.](image-url)
Taking into account the presented deliberation it is possible to conclude some general approaches concerning the designing such type of a mining support with such kind of welded joints. They are presented in the next chapter.

4. Investigation of mounting points
In the paper is presented the analysis of chosen critical mounting points that characterize with highest values of stresses. The two important constructional nodes are presented in figure 3. They are the lower mounting points of hydraulic props loaded with the roof mass and loading force, generated by them as well as the connectors mounting points. In figure 4 are presented upper props mounting.

Figure 3. Stresses for lower mounting points of props and lemniscate connectors ones.

Figure 4. Stresses for upper mounting points of props.
In figure 5 are presented stresses of bottom part of lemniscate connectors, near their bottom mounting points. The most loaded is, according to the figure, the mounted point of the front pair of connectors, so this point should be treated as crucial for this part of the support system.

Figure 5. Stresses concentration in connectors of the lemniscate mechanism.

The results of the virtual test for the prepared model of the V-shape mechanized support have been compared with the results of laboratory strength tests.

5. Comparative strength tests
To test the results of virtual FEM analysis of the support model it has been conducted the laboratory strength tests. The results presented in the paper concern the initial phase of analysis related with investigation of simple specimens of welded joints typical for analyzed mounting points (figure 6).

Figure 6. Stresses concentration in connectors of the lemniscate mechanism.
The presented exemplar results of laboratory test show that although general results of obtained values of stresses are similar to FEM results, the course of cracking differs. It suggested that the precise model of the support should include the characteristics of dissimilar joints. It is particularly important in the case of mechatronics models intended for mechatronics function simulation [30-32].

6. Conclusions
The results presented in the paper show that depending on the method of modeling and simulation of virtual models of machines it is possible to obtain general information about their behavior under load but it is problematic to obtain specific information concerning the course and evolution of cracking. Especially the direction of roof loads could significantly change the distribution of stresses. The conducted works allows beginning of the investigations aiming to elaborate the design of the welded mounting points with strengthened construction. It is also possible to conduct tests considered with improving the welding technology of manufacturing these joints. In these investigations is used the environment for mechatronics functions simulation. It allows conducting the analysis taking into account the program of a machine operation.

The presented finite elements analysis of described type of mechanized roof support was conducted to improve the design of its mounting points as well as to improve the material selection. Secondly, its objective was to improve the stress pattern, observer near the mounting points to match it to the different stratification systems of hard coal seams. The result of the work was a proposal of design corrections of the most loaded constructional nodes of the support.

7. References
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