Influence of mounting on hanging bolt lifetime

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Abstract. The main objective of this article is analysis of the hanging bolt failure that forms part of the weight transfer device. The base material of this bolt was protected by a surface layer to prevent corrosive influence of the environment. This bolt was used in combination with another screw of the same type to fix the movement of the device in the horizontal direction. This device operates by means of a hydraulic circuit at the rear of the agricultural machine and performs a vertical axis movement. The fracture surfaces of the bolt failure were evaluated on a thermo-emission scanning electron microscope. In the next part of the experiment, the micro-purity and microstructure of the material of the damaged hanging bolt was evaluated by optical microscopy. The main benefit of this article is the study of hanging bolt failure depending on the mounting design condition and from the way of its loading. Knowledge from this research is important to ensure safety with handling and protecting heavy loads from damage.

1. Introduction
Lifting and handling of heavy loads are governed by standards, laws and regulations of safety at work. These standards are supplemented by regulations to make work more effective, eliminate accidents at work and damage to property resulting from non-compliance or non-acceptance of lifting capacity. For this reason, the lifting and loading devices indicate the dimensions and load capacity that ensure the best handling of loads [1]. The hanging bolt was broken during transport of a load in difficult terrain. The bolt was part of the manipulation frame that was doing the vertical movement. The bolt fixation was horizontal with the possibility of position correction to ensure the functionality of the whole frame. The assumed loading force had a bending character. For this type of load, a combination of two bolts was chosen so that it was evenly distributed.

2. Experimental material and methods
As an experimental material, a damaged M12 suspension bolt of material C 15 was provided figure 1. This material is steel of usual properties, suitable for cold forming and predetermined for cementing with a medium core strength after quenching. The suspension bolt was made by die forging technology. Steel is less suitable for the formation of protective surface layers by the electroplating method. The load capacity of the bolt is 340 kg when loaded in the load axis. If the load is at an angle of 45° the load capacity is reduced to 240 kg. The applied weight per pair of such hanging bolts was 200 kg. At this weight, one of the two bolts was broken. This bolt was mounted in the frame incorrectly at an angle figure 2. The energy dispersive spectroscopy method was used to verify the presence of chemical elements according to the prescribed chemical composition. The EDX detects the entire X-ray spectrum simultaneously and sorts the photons with different energies per element.
Photons are further converted into an electrical signal, which is evaluated as an energy spectrum [2]. The method of optical microscopy was used for evaluation of material purity, surface layer and defects on the bolt surface. The samples were prepared metallographically, polished without etching. The microstructure was evaluated by optical microscope. For this analysis, the samples were etched with Nital. The method of scanning electron microscopy was used for the evaluation of the fracture surface. Its advantage is high resolution, high magnification and depth of field [2]. Vega 3 Tescan thermo-emission scanning electron microscope was used for fracture surface SEM analysis. The sample was ultrasonically cleaned in isopropyl alcohol medium.

3. Results and discussion

To verify the presence of chemical elements according to the prescribed chemical composition, the method of energy-dispersion spectroscopy was used, which proved the absence of five chemical elements, in particular P, S, Cr, Ni and Cu (table 1). The absence of these elements can affect the reduction of material properties such as strength, hardness, machinability and corrosion resistance [3].

| Material sheet | Damaged hanging bolt |
|----------------|----------------------|
| C (%) | 0.13–0.20 | C (%) | 0.22 |
| Si (%) | 0.15–0.40 | Si (%) | 0.31 |
| Mn (%) | 0.60–0.90 | Mn (%) | 0.51 |
| P max. (%) | 0.04 | P max. (%) | - |
| S max. (%) | 0.04 | S max. (%) | - |
| Cr max. (%) | 0.25 | Cr max. (%) | - |
| Ni max. (%) | 0.30 | Ni max. (%) | - |
| Cu max. (%) | 0.30 | Cu max. (%) | - |

The hanging bolt had a corrosion-resistant layer on the surface. In the non-etched condition, this layer was evaluated to be uneven with the local presence of areas with its complete absence. The average layer thickness was 2.98 µm. The analysis of determining the chemical composition using the energy-dispersion spectroscopy method showed that it was a Zn layer (figure 3). In another part of the experiment, the micro-cleanness was evaluated in the longitudinal section in the non-etched state.

The presence of non-metallic inclusions, in particular, sulfides and oxides, was visible in the hanging bolt material. The shape, distribution and quantity of the given inclusions were evaluated to the level 3 of the standard series according to STN 42 0471, which allows further use of the material (figure 4).
In the etched state, the microstructure of the material and possible presence of forging defects were evaluated. The metal matrix was formed by a fine ferritic-pearlitic microstructure (figure 5). The perlite type was lamellar. On the surface of the bolt, there were visible forging defects, in particular, micro-relocations, a large number of which were oriented at an angle of 45° (figure 6). Such defects may indicate a later extension of surface micro-cracks towards the core of the material when the bolt is loaded [4]. Further, there were micro-cracks coming from the surface, extending more or less in the horizontal direction, and surface micro-cracks whose distribution was at an angle close to 45° (figure 7). The surface roughness after the forging process was very uneven (figure 8). These surface defects can have a negative impact on the fatigue lifetime [4–6].
Figure 7. Surface microcracks.

Figure 8. Change in surface roughness.

Observing the fracture area of the broken hanging bolt (figure 9), it was identified that it is a transcrystalline cleavage fracture. Occurrence of the dimpled micromorphology was observed only in the final quarry area of the fracture (figure 10). Cleavage facets were observed on the fracture surface (figure 11). Hanging bolt failure was probably caused by low nominal stress, which confirms a significantly smaller final fracture area compared to the rest of the fracture surface. Fracture of the hanging bolt was probably controlled by fatigue micromechanism. Such a failure is also correlated with the method of loading the bolt, which consists of a tensile component in combination with a one-sided bend [7–9]. This type of loading corresponds to an unsuitable method of mounting the bolt, where the bolt head does not evenly fit to the mounting surface. Corrosion of the fracture surface was observed and may be related to exposure of the exposed material to the atmosphere for a longer period of time. This corresponds to the visible corrosion of the pearlitic phase at an advanced stage (figure 12). Since the corrosion identified on the fracture surface is not the primary process of component failure and is merely due to the non-optimal time associated with sampling, a secondary electron detector was used to evaluate the fracture surface. This detector is important for evaluation of fracture surface micromorphology.

Figure 9. Fracture surface.

Figure 10. Area of dimple micromorphology (from figure 9 – a).
Figure 11. Cleavage facets (from figure 9 – b).

Figure 12. Corrosion of fracture surface (from figure 9 – c).

4. Conclusion
In terms the very assembly of the bolt, it is very important in fatigue character of loading that the bearing surface of the bolt head is parallel to the surface on which the bolt is to be tightened. This condition was not met during assembly and thus another bending component of the applied force was introduced into the load method. The tightening torque of the lock nut must also be observed. This fact in combination with unsatisfactory surface roughness, the presence of forging surface defects, and the absence of alloying struts, could lead to premature failure of the bolt under a load less than the prescribed maximum load of the hanging bolt. It is also necessary to consider a method of loading the carrier itself, in which a pair of hanging bolts mounted in the carrier frame are subjected to a force at a constantly varying angle. This means that the condition is not met in terms of the angle force application, which should be static and be $45^\circ$, or the force should act in the axis of hanging bolt stress. From the material and constructional point of view, the use of this hanging bolt type is not an optimal solution for the given stresses.

5. References
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