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The Effect of Periodic Inspection and Safety Criteria on the Service Life of Steel Construction Conveyors

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Abstract
Steel construction structures are seen in many different applications in our country and in the world. However, the periodic maintenance of these steel construction products is explained by national and international laws and regulations. According to the relevant regulation in our country, it is obligatory to carry out periodic inspections of these constructive structures, which are referred to as machinery and equipment, once a year. As in many facilities, it is obvious that these structures are the main elements of the facility and will be used throughout the life of the facility. It is not clear under which conditions these structures, which are generally produced using structural steels and which are connected by welding or bolts, will be examined in the periodic inspections. As a result of the research on the lifetime of general structural steels, it has been proved by many researchers that these structures have an infinite life if they reach the number of million repetitions. However, the life of welding or bolts, which are the connecting elements of the structure, remains uncertain. In this study, accident breaking studies were carried out by detailing the damage due to a tragic accident in a steel construction that has served for about 36 years. By keeping company and personal information confidential, the steel structure and bolt connections of the construction were examined in terms of strength, hardness and microstructure, and the results were detailed.

1. Introduction

Belt conveyors are used for the transportation of bulk materials, such as ore, coal e.g., along a horizontal or an inclined conveyor track and can be used in various operational environments [1]. The handling of bulk solids is generally associated with significant wear on equipment and components. This is caused by either permanent or temporary contact between bulk solids and a wear body, e.g., component walls, tools, etc., with simultaneous relative movement or impact [2]. The researchers are widely investigated the failure mechanism of conveyor components. V. V. Poovakaud et al. are studied the fretting fatigue in high strength steel bolted connections [3]. M. Sundar et al. are investigated the corrosion behavior of conveyor chain pin [4]. W. Bochnowski et al. are researched the damage characterization of 330Nb alloy wire conveyor belt under carburizing atmosphere [5]. M.A. Khattak et al. are studied the failure of 430 welded steel plates for conveyor belts [6]. D. R. H. Jones is investigated the fatigue failure of drums for conveyors [7]. As the researchers mentioned, there are many reasons for improving equipment reliability [8], [9]. Unfortunately, the more catastrophic failures, such as whole of structural collapse, have been experienced and resulted as tragedy. These kinds of tragedies could be sourced by improper design or inaccurate assembly, insufficient maintenances, and overloads. However, the monthly and annual maintenance procedure could be summarized as, belt slippage, roller seizure, gearbox checks, electrical component checks (such as, fuse, conductor, emergency stop), ball roller checks, and irregular vibration and noise checks [10]. As can be

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seen, even if detailed in the design criteria [11], the steel structure, welded areas and bolt connections are not taken into account in the periodic controls.

In this study, collapse of a coal conveyor has been investigated. The steel components, welded zones and bolt joints have been studied in terms of corrosion, strength, hardness, and microstructural analysis. Location and time information is hidden due to personal data protection law.

2. Material and Method

The conveyor, investigated in this study, has been established 36 years ago from the collapse time. Conveyor has been designed as 167 m long and 14° incline angle, the final peak level was 45 m, above the ground. The structure of conveyor has been constructed as 23 different galleries. And each gallery has been combined with 138 pieces of M20 bolt joints to the other. Each gallery was 12 m long and nearly 11.7 tons. The conveyor has been designed and built on two tubular central and two sliding end supports, and total weight is 423.708 kg. The calculated wind load is vertically 12.369 kg and laterally 131.676 kg, and the snow load is 75.150 kg. The full capacity coal load is 131.000 kg. Under these loadings, the maximum shear and tensile stresses per bolt are nearly150 and 200 MPa respectively. But unfortunately, the pre-tension and torque level of bolts couldn’t be determined. For that reason, the design safety factor for the bolts could be calculated as 2.5 - 3.0.

It is detected form Technical Sheets of the conveyor that, St3Sx class structural steel was used for construction, the chemical composition is given in Table 1. This structural steel class is known as Poland Standard (PN-88 H-84020). And it is equivalent to DIN 17100 USt37-2 (S235JRG1) [12].

Table 1. Chemical composition of St 3Sx (wt.%).

C	Cr	Cu	Mn	Ni	Si	P	S	Fe
0.22	0.30	0.30	1.10	0.30	0.07	0.05	0.05	Bal.

The M20 bolts and nuts, surrounded on the edge of gallery, are detected as 8.8 and 10.9 class. On the lower segment of the gallery, which was loaded both tensile and shear stress, the bolts and nuts were selected as 10.9 class, other ones were 8.8.

To determine the corrosion and fatigue evidence of steel, the structural steel samples were taken from unstrained part of the wreckage. The samples were taken from the "U" and "I" type profiles, which are the carriers of the gallery. These profiles were chosen from the lower segment and the side wall, representing the entire gallery (Figure 1). Profile samples taken from the lower segment were selected from the region with both coal accumulation (Sample type A) and non-accumulation (Sample type TB), and it was tried to determine whether the coal affected the mechanical properties. In addition, one sample (Sample type U) was taken in the ceiling profile.

Figure 1. Structural steel samples.

Bolt and nut samples were also chosen in a variety to represent the whole gallery and larger numbers of samples were selected from the lower segment, where the coal dust accumulation located (Figure 2).

Steel tensile test samples were machined according to the TS 138 EN 10002, and the tensile tests were carried out according to the ISO 6892. Bolt and nut tensile tests were carried out according to the ISO 898-1. The tensile tests were carried out on 600 kN Dartec servo-hydrolic test machine.

Sections of steel and bolt samples were grinded by using the Metcon Forcipol 2V rotating polishing machine with various grades of SiC papers up to 2400 grid. Specimens were subjected to fine polishing by using 1 μm diamond paste and then final polishing by colloidal-silica suspension. Polished specimens were immersed into Nital solution for 5 s and washed with alcohol. Leica optical microscope and Clemex Image Analyzer were used for microstructural examinations.

The hardness tests were carried out on Zwick micro-hardness test device and results were reported in Vickers unit.

3. Results and Discussion

Due to the fact that the A2 profile was in the lower segment covered with coal dust, the corrosion effect on the sample was tried to be investigated. In the sample taken on this profile, it was observed that there was only corrosion on the outer surfaces, but no corrosive effect penetrating into the base metal occurred, and it was determined that the material microstructure was in accordance with the standard "Beynitic" structure of St3Sx structural steel (Figure 3).

Figure 2. Bolt and nut samples.

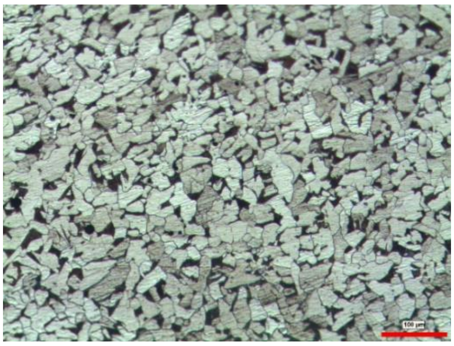

Figure 3. Microstructural image of A2 sample.

However, in the examination, made on the welded part, corrosion and crack formations were observed, and showed in Figure 4. But even if the cracks were critical size, the lack of load bearing functions of the welded seams was not considered as the main cause of collapse.

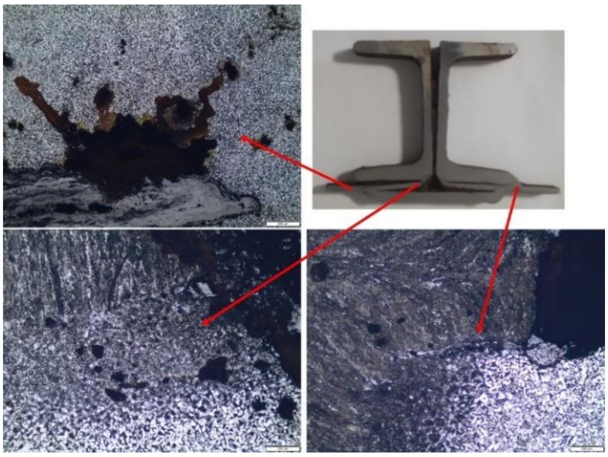

Figure 4. Welded zone of U type profile.

In the examination made on the bolt, it was determined that the corrosion layer (Figure 5) observed on the surfaces did not penetrate the material, therefore corrosion did not adversely affect the mechanical properties of the material. The hardness change of the bolt material from the outside to the inside was investigated by making micro-hardness measurements. As seen in Figure 5, it was observed that there was no microhardness difference between the outer surface and the inner part of the bolt, the hardness results preserved the trend and mean value is about 320 HV.

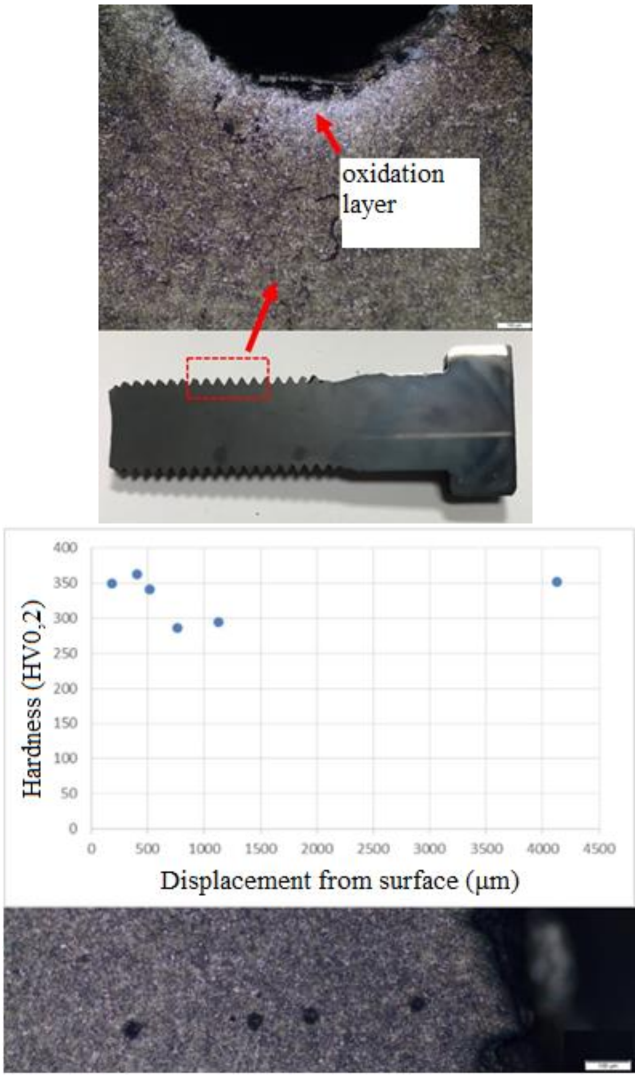

Figure 5. Oxidation layer on the bolt outer layer and hardness.

According to the tensile tests seen in Figure 6, it has been understood that the St3Sx structural steel, which forms the structure, meets the yield and tensile stresses and % elongation at break values determined in the standards. Accordingly, despite the 36-year service period, there was no decrease in strength in the samples taken. For this reason, it has been understood that all profile drawing specimens comply with the design standards [13].

It was understood that coal dust accumulated in the lower segment had no effect on the steel, since no strength reduction was observed in the samples coded A1-A2 and A3 taken from the lower segment.

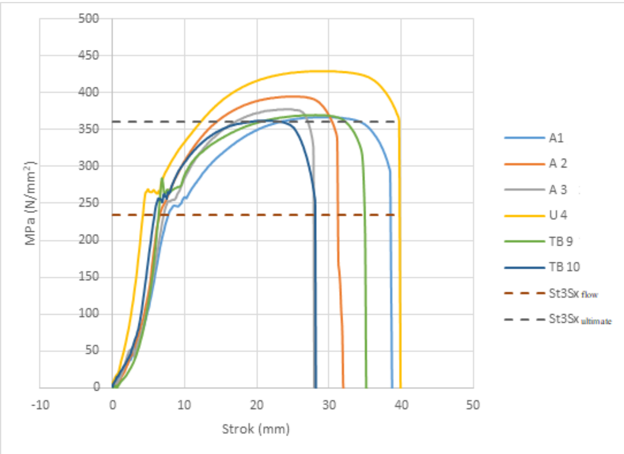

Figure 6. Tensile test results of steel samples

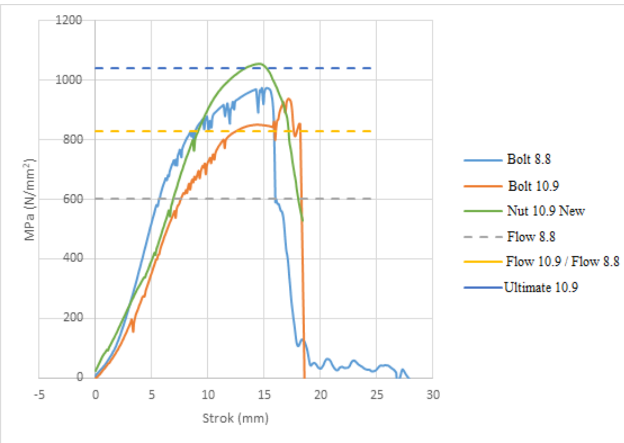

Figure 7. Tensile test results of bolt and nut.

In the tensile tests performed on the bolts, the tensile damage area in the 8.8 class bolt is in the bolt thread region as expected (Figure 7 and Figure 8). This bolt met the tensile strength with yielding [13]. In the tensile tests performed with two different bolts of 10.9 class, the damage is in the region of the nut threads (Figure 9). According to yield and tensile strength, 10.9 bolt-nut connection could not meet the standard values [14]. According to ISO 898-1 and 898-2 standards, the yield limit of the nut material is expected to be higher than the bolt material under all conditions, and it is known that the damage should be on the bolt instead of the nut.

Accordingly, a nut whose class is known with certainty was obtained and a 10.9 class bolt was subjected to a tensile test again (Figure 9). The 10.9 quality bolt taken on the gallery and the newly supplied 10.9 class nut were pulled together and this time no damage was observed on the nut. It has been observed that the connection (bolt - nut) has the strength values specified in the standard.

Figure 8. Bolt damage of 10.9 class.

Figure 9. Nut damage of 10.9 class.

Accordingly, a nut whose quality class is known with certainty was obtained and the 10.9 quality bolt was subjected to the pull test again (Figure 10). The 10.9 quality bolt taken on the gallery and the newly supplied 10.9 quality nut were pulled together and this time no damage was observed on the nut. It has been observed that the connection (bolt - nut) has the strength values specified in the standard.

Figure 10. 10.9 Bolt and Nut match.

According to the tensile test results, since both quality bolts are in M20 dimensions, it is thought that an 8.8 quality nut was attached to the 10.9 quality bolt that should be used in the lower segment. According to the video records, in the area that is thought to be the first broken gallery, parts of the damage type observed in the tensile tests were found in the 10.9 bolt-nut pair used as the fastener at the lower segment joint (Figure 11).

Figure 11. Nut stripped of its threads in damaged gallery lower segment.

In order to determine the cause of unexpected damage to the nut threads, the damaged nut, the undamaged 10.9 quality nut removed from the gallery, and the newly supplied unused 10.9 quality nut thread regions, the microstructure of the completely stripped nut was coarse-grained and 170 HV hardness, as can be seen in Figure 12 (a). It has been determined that (b) sample is finer grained and has a hardness of 220 HV, and sample (c) has a “Martensitic Needle-like” structure and has a hardness of 300 HV. According to both hardness and microstructure images, some nuts used in the gallery should be 10.9 quality, but it strengthens the thesis that they are manufactured from 8.8 quality nuts.

As detailed, structural steel strength level was detected that, these steel components are still in their service life. The corrosion effects are located only the outer surface and no evidence is detected in main core. However, the welding seams of steel joints contain heavy corrosion cracks and corrosion effect reach the interior side. But the good part of this situation is, the welded joints were not subjected to loading.

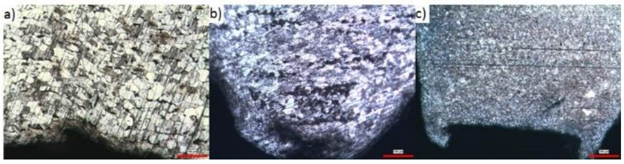

Figure 12. Microstructures of a damaged tensile tested nut (a), an undamaged grade 10.9 nut (b) remove from the gallery, and a newly supplied unused grade 10.9 nut (c).

Additionally, the corrosive effects of coal on the structural steel have been studied and detected that, the corrosion rate rises after %55 moisture [16]. The coal carried on related conveyor has a % 27 moisture. This is another reason why the corrosion effect remains on the steel surface. Similar surface corrosion effects were detected in bolts and nuts. The bolt strength was also detected in both the 8.8 and 10.9 class. But, due to disastrous mistake, the 8.8 nuts were attached to the 10.9 bolts.

Even if the designed safety factor for bolts is over 2.0, during the service life of thirty years, the vibration and dynamic loads could be responsible for the loosening. For that reason, the stress per bolt especially on the lover side has been increased and reach the critical level. During the inspections of collapsed construction, it is expected that the lover side of conveyor bridge was completely closed, and any manholes were not designed. This design insufficiency prevents the periodic control of bolt torques. Additionally, during the inspection of collapsed construction, the lover side of the conveyor bridge has a gap of 6 x 0.5 meter. Over the thirty years of service life, the coal dust takes place in this gap and keeps water in it (as seen in Figure 1). The coal dust accumulation reaches nearly half of the gallery and creates 116.000 kg additional load. This additional load is nearly one fourth of death weight of construction because bulk density of coal dust heavier than the coal grains that carried.

The structural steel and bolts can both provide fatigue-free service life. Unfortunately, the improper assembly and design insufficiency combination can cause as dramatic collapses and death of workers.

4. Conclusion and Suggestions

According to the design parameters, structural steels can provide fatigue-free service for many years.

If the coal moisture remains below 50%, the corrosion effect on structural steel is only superficial. Corrosion effect of 36 years old coal dust is only superficial in 8.8 and 10.9 class bolt-nut pairs.

The manholes are the design criteria that should not be forgotten and must be used for periodic control. The bolt pre-tension and torque level must be checked and prevented to loosen.

The gaps that will cause material accumulation must be checked. It should be noted that the material filled into the gaps will be in dust form and the bulk density will be heavier.

Incorrect assembly and unpredictable loads can cause catastrophe. For this, a risk assessment should be made.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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