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Araştırma / Research

FAILURE ANALYSIS OF AN UPPER BENDING CYLINDER BUSHING IN A PLATE MILL

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ABSTRACT

Premature failure of a bending cylinder bushing in a plate mill was investigated in this study. Visual, chemical and microscopic analyses were performed to detect the possible reasons of this failure and possible measures to be taken were mentioned not to be encountered for this type of failures in the future. No traces of welding were observed in the performed studies. Intensive elongated MnS inclusions, fatigue striations and splits from the grain boundaries were detected in the microstructural investigations. It was also proved that the base of the bushing was worked without chamfering. The importance of the removing hydrogen from the structure by annealing to decrease the hydrogen brittleness risk which would occur after the chromium coating process, and the chamfering of the bushing base to decrease the crack susceptibility was stressed.

Keywords: Failure analysis, bending cylinder bushing, hot rolling, fatigue

BİR LEVHA HADDEHANESİNDEKİ ÜST EĞME SİLİNDİRİ KOVANINDA OLUŞAN HASARIN ANALİZİ

ÖZ

Bu çalışmada bir levha haddehanesinde eğme silindiri kovanında meydana gelen erken hasar incelenmiştir. Oluşan bu hasarın sebeplerini tespit etmek için görsel, kimyasal ve mikroskobik analizler yapılmış ve gelecekte bu tip hasarlarla karşılaşmamak için alınması gereken tedbirlerden bahsedilmiştir. Gerçekleştirilen çalışmalarda herhangi bir kaynak izine rastlanılmamıştır. Yapılan mikroskobik incelemelerde, şiddetli bir şekilde uzamış MnS inklüzyonları, yorulma adımları ve tane sınırlarından ayrılmalar belirlenmiştir. Ayrıca kovan tabanının pah kırılmadan işlendiği de tespit edilmiştir. Krom kaplama prosesinden sonra oluşabilecek hidrojen gevrekliği riskini azaltmak için tavlama ile yapıdan hidrojenin uzaklaştırılmasının ve çatlak hassasiyetini azaltmak için kovan tabanında pah kırmanın önemi vurgulanmıştır.

Anahtar Kelimeler: Hasar analizi, eğme silindiri kovanı, sıcak haddeleme, yorulma

1. INTRODUCTION

Hydraulic cylinders are used in various types for different aims in many types of equipment. Cylinders convert fluid power into mechanical motion [1]. They are hydraulic actuators that are constructed of plungers that operate in cylindrical housing by the action of liquid. A cylinder consists of a cylindrical body (bushing), closures at each end, movable piston, and a rod attached to the piston. When fluid pressure acts on the piston, the

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pressure is transmitted to the piston rod, resulting in linear motion. The piston rod thrust force developed by the fluid pressure acting on the piston is easily determined by multiplying the line pressure by the piston area.

Hydraulic cylinders are also used to move the rolls which realize the rolling operation in the rolling mills. The work rolls deform during rolling operation towards the back-up rolls. Bending cylinders seal the work rolls onto the backup rolls by pushing the upper and lower work rolls in the vertical axis from the trunnion zones by means of hydraulic fluid inside the cylinder to achieve the desired crown values. The gap between the work and backup rolls are also calculated by the model considering the reduction ratio at the pass during rolling.

Failures can occur on the materials due to some reasons. Fatigue is one of the failures that can be encountered during the operation of the part. Fatigue may occur when a material is subjected to cyclic loading. If the loads are above a certain threshold value then a crack will begin to form at the stress concentration points. Eventually a crack will grow and reach a critical size; the crack will propagate suddenly and the material will fracture.

Bending cylinders are exposed to cyclic loading in their working conditions and if the cracks cannot be detected during periodical maintenances of the system then failure can occur. If the failed part and the operating conditions are analyzed in a detailed way, traces of failure can be detected and judged whether the failure is due to fatigue or not.

Many studies have been carried out on fatigue failures [2-4]. Fatigue striation spacing measurements were carried in some investigations [5, 6]; and models for the formation of fatigue striations have been put forward [7,8]. In the current study, fatigue formation in the bushing material which was made of S355J2 (EN10025-2-2005) was analyzed.

2. MATERIAL AND METHOD

Bending cylinder bushing in plate mill was investigated to find out why it failed during the early stages of its lifetime. Measured values of the elements in the failed cylinder bushing and chemical analysis which this bushing material should have are given in Table 1.

Cylinder stroke is 358.8 mm, working pressure is 275 bars, bushing material is S355J2, and working temperature is -20°C / +120°C for hydraulic cylinder system in this study. According to the contract in which the machine manufacturer describes the specifications and manufacturing conditions for the bending cylinder, chromium coating thickness over the bushing should be 25-30 µm. Outer diameter of the bushing is 203 mm and inner diameter (diameter of cylinder) is 165 mm. Although cylinder bushings' working lifetimes in this plate mill are about 10000 hours, the bushing under investigation failed after about 1000 hours of working.

General view of the broken cylinder bushing is given in Figure 1. Fracture occurred in the zone which is shown by the arrows in the Figure 1 and propagated along the periphery of the bushing.

Table 1. Chemical analysis of broken cylinder bushing

Material	C %	Mn %	Si %	P %	S %	Cu %
S355J2	0.23 (max)	1.70 (max)	0.60 (max)	0.035 (max)	0.035 (max)	0.60 (max)
Tested Sample	0.16	1.42	0.23	0.013	0.019	0.22

Figure 1. General view of the broken cylinder bushing

Technical schematic drawing of bending cylinder system is seen in Figure 2. Piston rod moves inside the cylinder by means of the fluid.

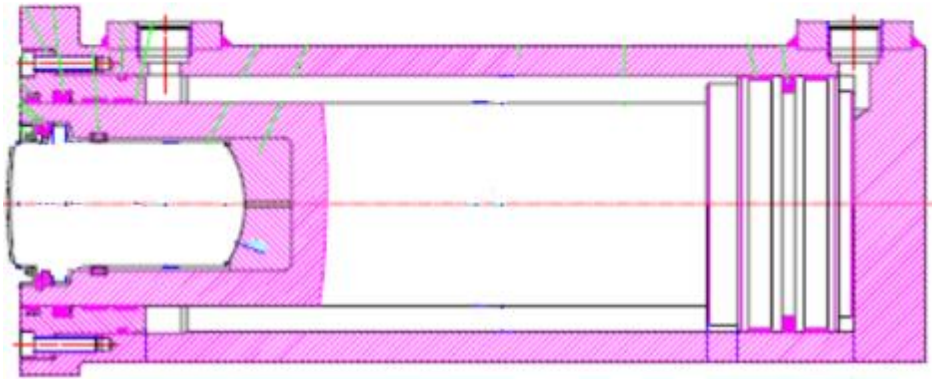

Figure 2. Technical schematic drawing of the bending cylinder system

The broken part was investigated to detect whether the part has welding or not. Fractured zone of the broken part was cleaned by sandpaper and etched by a nital solution (nitric acid + alcohol) for the macroscopic investigations.

Specimen which was taken from the fractured zone was prepared by metallographic methods for the microstructural investigation and microstructure was examined using Nikon MA 200 optical microscope (Nikon, Tokyo, Japan). Fracture surface of the part was examined using Jeol scanning electron microscope (Jeol JSM 5600, Tokyo, Japan) equipped with Oxford X-ray microprobe (EDX) unit (Oxford, UK). The thickness of the chromium coating on the bushing was also measured.

3. RESULTS AND DISCUSSION

The chemical composition of the material which the cylinder bushing is made is within the prescribed limits for steel S355J2. Etched surface view is seen in Figure 3. There is a long crack on the surface and it is observed that the crack propagated along the periphery of the bushing.

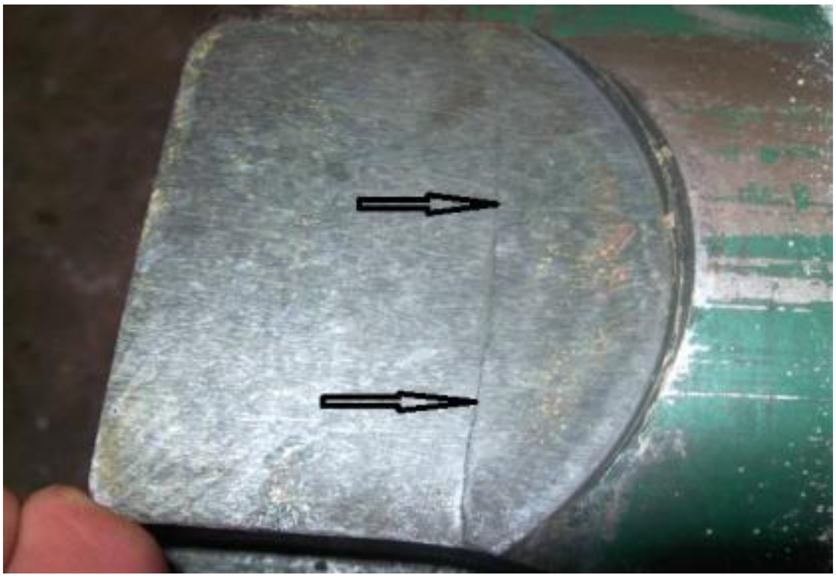

Figure 3. Surface view of the part after etching

It is seen that the general microstructure of the bushing material consists of ferrite and banded pearlite phases (Figure 4). Elongated MnS inclusions in the microstructure (Figure 5) show that the part was possibly produced from a processed forged bloom. These sulfide inclusions act as stress raisers and fatigue cracks initiate at these points [9].

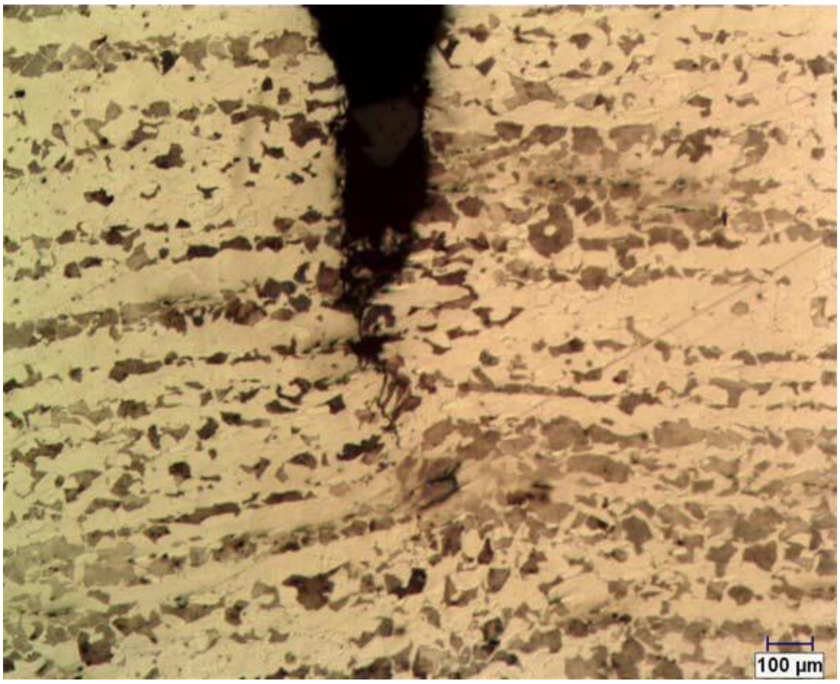

Figure 4. Image of the fractured zone

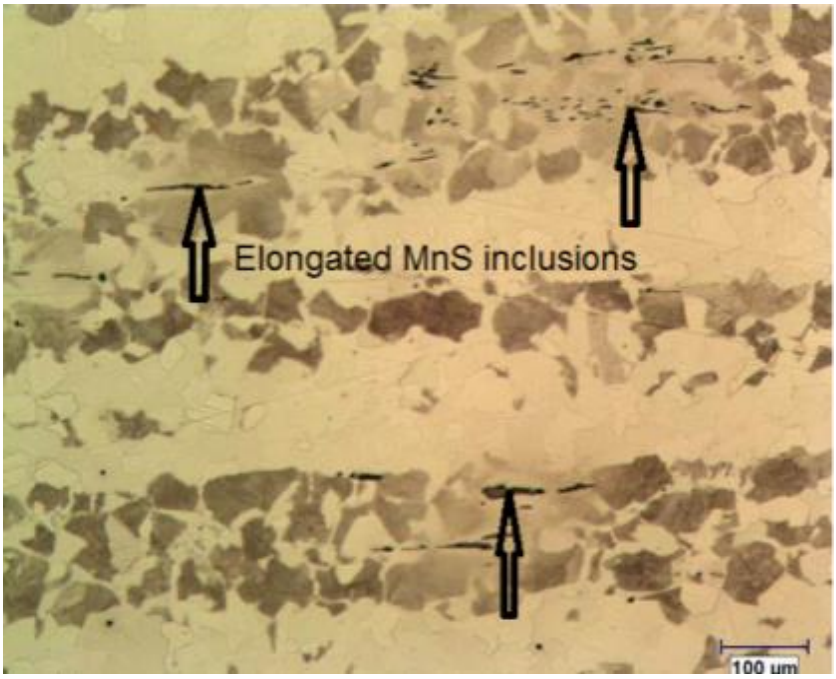

Figure 5. General microstructure of the part and elongated MnS inclusions

Chromium coating thickness measurements were also performed on the bushing whether the coating was between the limits written in the contract. It was detected from the coating thickness measurements that the measured thickness of chromium coating over the bushing confirmed the desired thickness value in the technical contract (Figure 6).

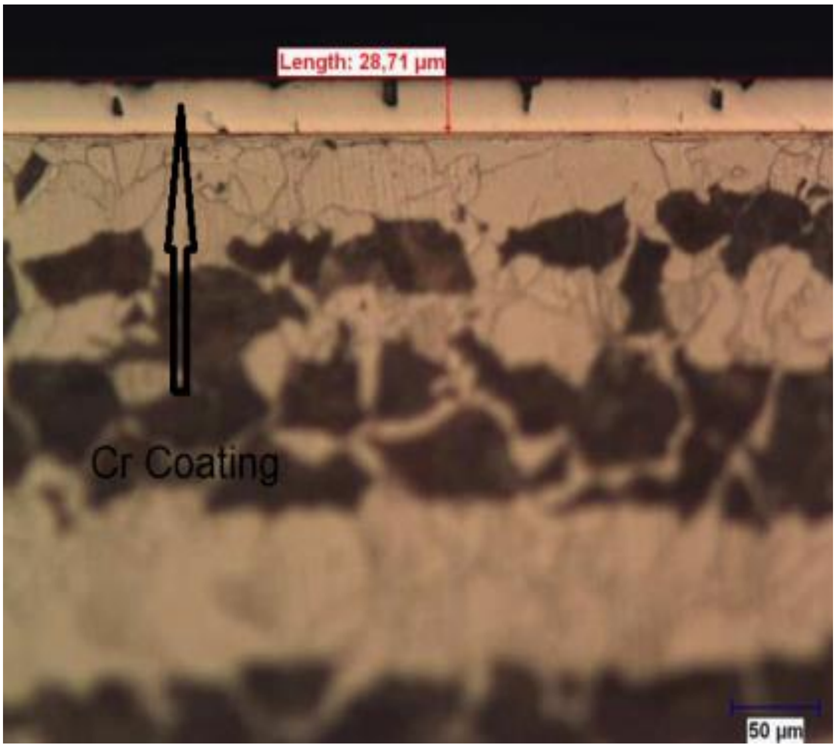

Figure 6. Chromium coating on the part

Specimen which was taken from the fractured zone was divided into two pieces from each other and broken surfaces were investigated in the SEM (Figure 7 and 8).

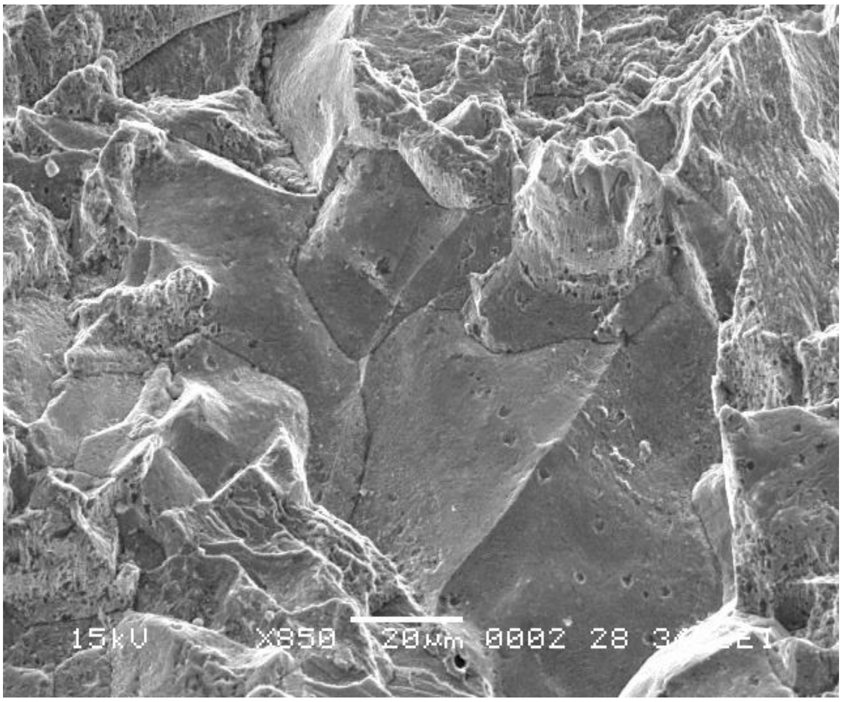

Figure 7. SEM image of the fracture surface

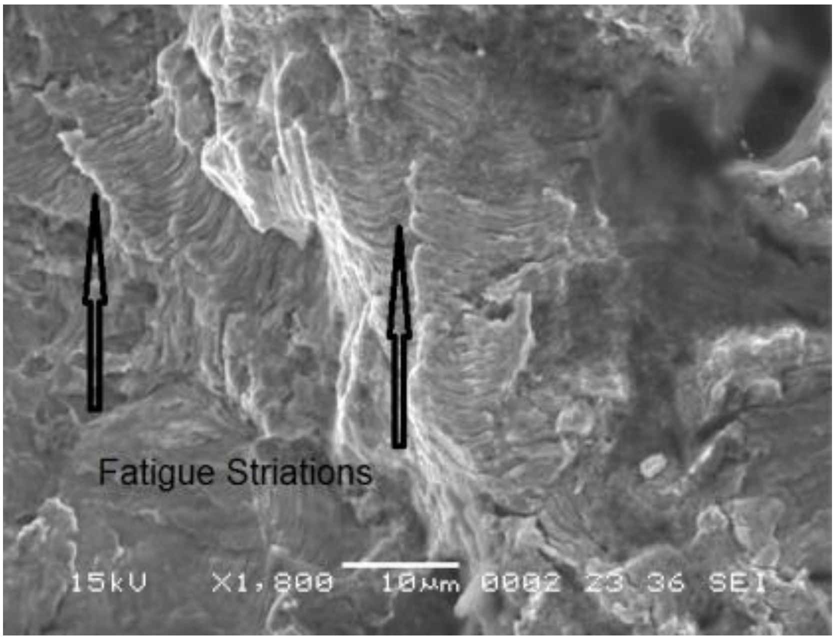

Figure 8. SEM image of the fracture surface

It was detected from the SEM investigations that fracture initiated from the grain boundaries. Furthermore fatigue striations were detected in the zone shown by the arrows in Figure 8.

Splits from the grain boundaries were detected on the broken surface investigations; these splits raise doubts that the part could pick up hydrogen during chromium coating process. Hydrogen may cause embrittlement of the material along selective paths, which can drastically reduce the resistance of a forged part to crack propagation resulting from impact loading, fatigue or stress corrosion [10]. Also, fatigue steps detected on the fractured surface show that fracture has occurred in a process by the time. This can be accepted ordinary as the part is thought to be exposed to the cyclic load. Removing the hydrogen from the structure by annealing the part at a proper temperature for a certain time can be useful to be able to decrease the hydrogen brittleness risk which would occur after the chromium coating process [11].

Welding or another manufacturing process which combine two or more pieces should not be used in the production of this type of parts. This condition was also pointed out in the contract as “bushing should be manufactured as a unique part”. No traces of welding process were seen in the performed studies. Intensive elongated MnS inclusions were detected in the microstructural investigations. The risk of creating sensitive zone for the crack initiation of these inclusions is very high.

It was also seen that the base of the bushing was finished without chamfering: this type of finishing increases the crack susceptibility since the crack propagated by initiating from the internal surface and the base of bushing.

4. CONCLUSIONS

The chemical composition of the material which the cylinder bushing is made is within the specifications. Traces of fatigue on the part were observed and can be attributed to the cyclic loads during working. Nonmetallic inclusions such as manganese sulfide detected in the microstructure can behave as stress raisers and fatigue can initiate from these points. Also, the part can pick up hydrogen during chromium coating process: hydrogen removal by annealing can be useful to decrease the hydrogen brittleness risk after the chromium coating process. Finishing the bushing base by chamfering can be effective to lower the crack susceptibility.

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