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Failure analysis on tube arm cylinder hydraulic excavator

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Abstract—The Failure on tube rod arm cylinder hydraulic excavator caused to lose production and processing time on mining site. Investigation included visual inspection, chemical analysis, metallography analyzes, and microhardness test. Tube material used high silicon material type while the standard used ST52 carbon steel type. The tube was broken and crack to several pieces. The chemical composition of the tube has different in sulfur and silicon content. From hardness test with micro hardness method, sample tube broken has lower hardness compared to standard hardness. Metallography analysis obtained the phase of tube has same phase with standard which is ferrite and pearlite phase but has different grain size. Based on this study, it can be resumed failure on tube is because impurities and different specification on raw material.

Keyword: *Arm Cylinder, Hydraulic Excavator, Tube*

I. INTRODUCTION

Tube hydraulic cylinder is part of hydraulic cylinder in heavy equipment hydraulic excavator. A hydraulic cylinder is one of mechanical part that used in hydraulic excavator. This cylinder has main function to force bucket or other attachment force through a linear stroke. Hydraulic cylinders get their force from oil. Oil has pressured inside the hydraulic cylinder and made the cylinder can be moved. Hydraulic cylinders are used in many equipment and machinery, in heavy equipment, cylinder hydraulic is used on excavators, bulldozers, and motor graders (Nicoletto & Marin, 2011).

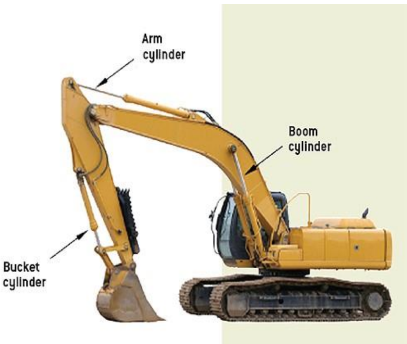

Figure 1. Hydraulic excavator

Broken tube can be obtained from many factors, like mis-operation or external factor. In this study we focused to determined root cause from raw material, because based on indication from mining site, there was some abnormal symptoms.

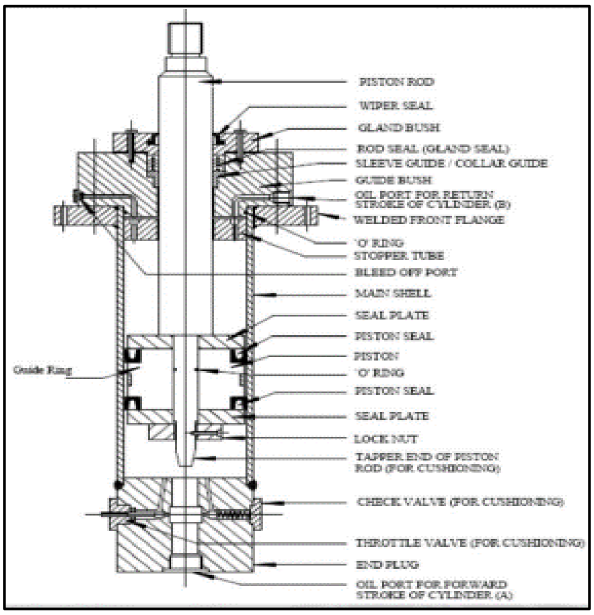

Figure 2. Hydraulic cylinder

II. METHODS

Figure below show broken part from the tube and it divided into several pieces. We did some test and analyze, to obtained data from piece of crack on surface and inner diameter tube.

Figure 3. Broken tube sample

For chemical composition test we used X-Ray Fluorescence tools, then used metallurgy microscope and micro vickers hardness test to get metallography and hardness test data. A specimen from tube was cut for metallography analysis and microhardness test. The specimen was mounted in resin, and then grinding and polishing process using metallographic standard preparation. For metallographic analysis the specimen was etched with nital 2% but for hardness test the specimen was not etched, then analysis on magnification 100 X – 500 X. And visual analysis we used dino-lite portable microscope to analysis surface fracture area.

III. RESULTS

A. Chemical composition test

Chemical composition test with X-Ray Fluorescence has result in table 1 below. The sample is cleaned with alcohol to make sure no paint left on tube surface.

Table 1. Chemical composition test

Element (%)	Sample (%)	Standard ST52 (%)
Si	1.74	0-0.55
Mn	0.534	0-1.60
P	0.04	0-0.045
S	0.094	0-0.045
Fe	Balance	Balance

B. Metallography analysis

Analysis microstructure was used inverted metallography microscope after etching process, the result in figure below

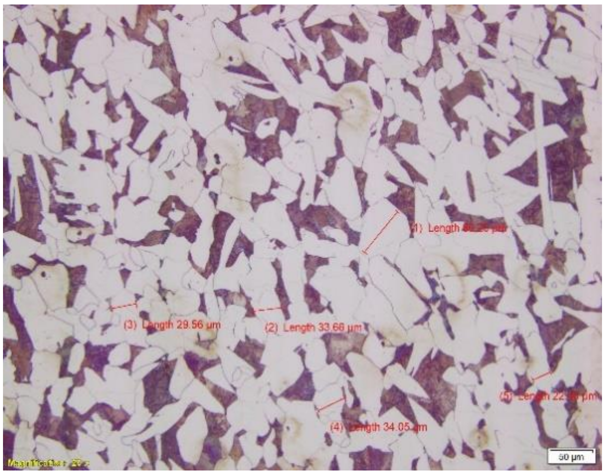

Figure 4. Broken Tube Sample Microstructure

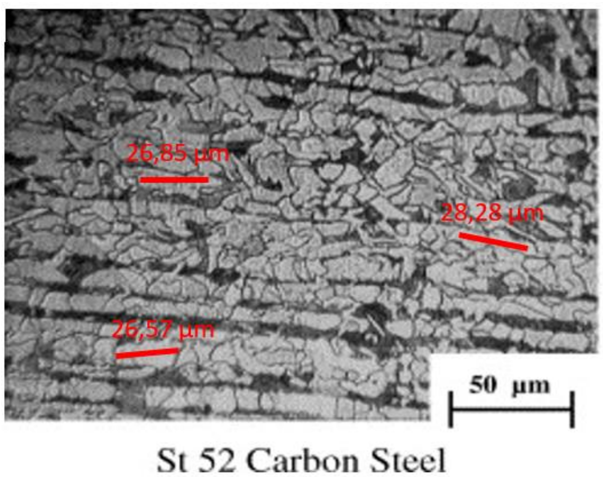

Figure 5. Reference Sample Microstructure

C. Hardness test

Hardness test with micro-Vickers tools has result in table 2.

Table 2. Hardness test result

No	Sample (HV)	Standard ST52 (HV)
1	169.7	229.5
2	173	226.4
3	183.7	227.8
4	178.7	208.5
5	185.2	221.5
Average	**178.06**	**222.74**

IV. DISCUSSION

A. Chemical composition analysis

Based on a comparison of the sample broken cylinder and reference ST52, from the results of the chemical composition test, there was a difference in the presence of a high Silicon element (1.74%) compared to the standard Silicon element at standard (0.55%) and the presence of Sulfur (0.94%) exceeds the standard ST 52 maximum (0.045%). Sulfur (S) as well as phosphorus (P) has a tendency to segregate as block or gas segregation. This will happen especially if the smelting process, especially steel, is not carried out carefully and there are lots of fluctuations. Sulfur is one of the elements is also included in the group of unwanted elements. Mangan (0.5% – 0.9%) is an element added to prevent the bad effects caused by Sulfur. Beside that effect to much sulfur content tends to cause brittleness and reduce weldability.

Silicon in small amount was mixed in rolled steel when it is used as a deoxidizer. But when these filler metals are used for welding on clean surfaces, the resulting weld metal strength will be massively increased. Because weld metal strength increase, the ductility was decreased and could made cracking problem. (Keerthivasan et al., 2022) These two elements can also function as impurities when they react with element O in the steel and can cause fracture or failure.

B. Metallography analysis

Using an optical microscope. In this tube arm cylinder broken analysis, the thing that is of concern is the phase contained in the arm cylinder broken part. Based on the results of the microstructural analysis, the broken tube arm cylinder sample consists of ferrite and pearlite phases which have ductile and tough properties. Whereas the reference ST52 also consists of ferrite and pearlite phases which have ductile and tough properties. Based on the analysis of ferrite grain size, it can be seen that the grain size of ferrite up to the arm cylinder sample looks larger (34-60 µm) than the grain size of Reference ST 52 ferrite, which is (26-28 µm) (Zhou et al., 2020). The larger the grain, the lower the hardness and tensile strength, but the better the ductility (Khodabakhshi & Gerlich, 2020). As explained in the Figure 6.

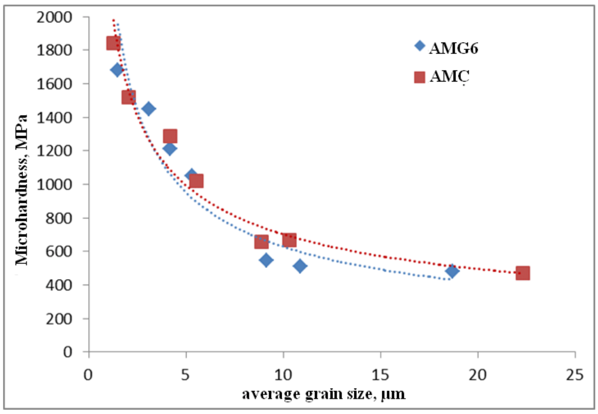

Figure 6. Correlation Hardness and Grain Size

C. Hardness analysis

Based on the hardness test with a microhardness tool, it can be concluded that the hardness of the tube arm cylinder part material is 178.06 HV (below 10 HRC) and on the ST 52 reference tube is 222.74 (19.54 HRC). So based on the microhardness test, it can be seen that there is a hardness difference of around 10 HRC between the arm cylinder and the reference ST52. This can reduce the strength of the tube cylinder and be a starting point for fracture and failure. And according to the initial hypothesis in the microstructural analysis, the larger the grain size, the lower the hardness (Wang et al., 2021). Pressure was happened in tube cylinder is internal pressure from oil and external pressure from the mounting on hydraulic excavator.

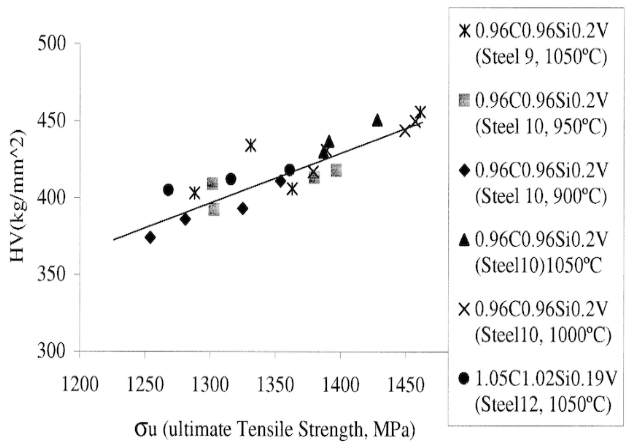

Figure 7. Correlation hardness and tensile strength

D. Visual analysis

With dino-lite portable microscope we examined the surface broken area, the surface has rough and smooth fracture area which indicated is spontaneous fracture. No beachmarks or striation seen, which indicated fatigue failure not the main fracture for this failure.

Figure 8. Surface sample fracture

V. CONCLUSION

The cause of the failure of the tube arm cylinder part is indicated by the presence of Silicon and Sulfur impurities that exceed the standard amount and the difference in hardness material specifications between the tube arm cylinder part and the ST52 material reference. Based on the hardness test with a microhardness tool, it can be concluded that the hardness of the arm cylinder part material is 178.06 HV (below 10 HRC) and on the ST 52 reference tube is 222.74 (19.54 HRC). So based on the microhardness test, it can be seen that there is a hardness difference of around 10 HRC between the arm cylinder and the reference ST52. This can reduce the strength of the arm cylinder and be a starting point for fracture and failure.

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