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Analysis of Spring Damage in the Chamber Actuator

Raven Rullyapatra Nasution[1], Rudi Saputra[2]
[1]Institut sains dan Teknologi Nasional, Indonesia, revan.rully@gmail.com
[2]Institut sains dan Teknologi Nasional, Indonesia, hajirudi09@gmail.com

*Corresponding Author: revan.rully@gmail.com[1]

Abstract: Spring, which has the function to help the valve operate so that it can be fully closed and fully open, has a very vital role in the continuous operation of the chemical industry. When a problem occurs, muddy fluid is found in the spring actuator chamber which causes the valve not to operate and not be in full close condition. The purpose of this study is to find the causes of the Spring Actuator failure in the chemical industry. This research was specifically directed at a broken Spring Actuator to determine the cause of the failure/damage. The tests carried out were: fractography, metallography (microstructure), chemical composition analysis, hardness test, and scanning electron microscope (SEM) energy dispersive x-ray (EDX) analysis. The results of the macrographic examination showed that the spring fracture had 2 fracture surface patterns. Spring B has a brittle fracture where the shape of the fracture is more even and does not show residual fracture. While springs A, C, and D experienced ductile fracture. The results of metallography found corrosion products in the surface area of the spring. There are non-metallic inclusions in the form of sulfides and microvoids. The microstructure is tempered martensite. From the results of the chemical composition of the spring material, it still meets the JIS G 4801 grade SUP 12 standard with the addition of Silicon and Chrome. The hardness test results have a hardness value of 518.4 HV. The spring hardness value is above the maximum hardness limit of SUP 12 material. The SEM test results of the spring sample show the presence of non-metallic inclusions with elongated morphology and micro-sized voids. The results of the EDX test showed a Sulfur content of 4.71 wt% in non-metallic inclusions and the content of Fe and O elements in the defective holes which were corrosion products. From this study, it is known that the factors causing damage to the springs are manufacturing process errors, material defects, and corrosive environments.

Keywords: Spring, Void, Failure Analysis, Corrosion, Metallurgy

INTRODUCTION

In Indonesia, more and more industries in the energy, oil and gas, and chemical sectors have been operating for quite a long time. The production process in a chemical industry is very complex, involving various kinds of equipment and instruments which do not rule out the possibility of failure/damage during operation. Valves is one of the components that are widely used in various industries. In an industry, especially one that is engaged in liquid processing, of course there is a piping system that functions as a place for the liquid to flow. Each series of pipes definitely has a tool that is used to regulate the amount of flow so that the processing process can run as determined. This tool is called a valve. There are many problems that occur with this valve during operation, these problems include: wear, erosion, corrosion, cavitation and others. The valve is composed of several components, including: Body, bonnet, trim, disc, actuator, and others. The part that is often and get seriously damaged in the spring is the actuator.

Failure will affect the operating costs in the industry, because failure means that the components need to be repaired or replaced. The spring is part of the valve actuator and the function is so that the valve is fully closed (MV=0%) and fully open (MV=100%). The condition of the spring actuator in the operating process is in a dry environment. At the time of the incident it was discovered that the valve was not in a fully closed condition. After inspection, muddy fluid was found in the spring actuator chamber and there were 4 broken springs (1 spring actuator chamber has 8 springs) which caused the valve not to fully close. 4 springs were broken and 3 springs were not broken (total 7 springs). The type of pump impeller shaft material is Silicon chromium steel (ASTM A401). This research tries to find the cause of Spring Actuator failure in the chemical industry. The problem found was that it was broken due to corrosion attack. Previously in the industry there had been no attempt to analyze the causes of this damage.

METHOD

The method for preparing this report uses analytical methods by carrying out fractography, metallography (microstructure) tests, chemical composition analysis, hardness tests, and scanning electron microscope (SEM) energy dispersive x-ray (EDX) analysis. Fractography is carried out to determine the micro profile of the fracture surface. Apart from observation through photography and through a stereo microscope, the sample is also measured in all its dimensions to determine whether the sample experiences dimensional changes caused by deformation when it is damaged.

Metallographic testing is carried out to determine the microstructure contained in the material. Examination of the microstructure aims to observe the phases on the surface of the shaft material. Hardness testing carried out in this research used the Vickers (HV) method. The Vickers hardness test uses a pyramid-shaped diamond pressing indenter with a peak angle of 136° and a load of five kilograms.

In this chemical composition test, the test object can be immediately analyzed by an Optical Emission Spectrometer (OES) with the completion of burning argon gas on the surface of the test object with a content of 99.99%. Results can be printed out for reports. SEM–EDX analysis was carried out to observe the condition of the fracture surface with a higher magnification than macrography and to determine the elements contained on the damage surface that may have contributed to the cause of the damage.

RESULTS AND DISCUSSION

Fractographic examination

Figure 1. Visual material identification carried out on broken springs

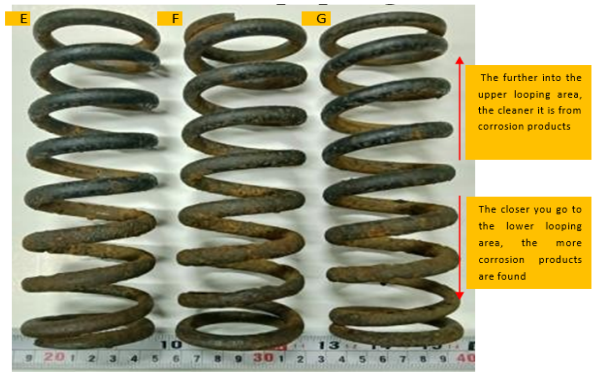

Figure 2. Visual material identification carried out on springs that are not broken

From the results of visual observations of broken and unbroken springs, it can be seen that at the bottom of the spring the most corrosion production was found. Meanwhile, at the top, only a few corrosion products were found. It can be concluded that the further down you go, the more production you find on spring. This is because the position of the spring experiences fluid deposits in the form of mud. The results of macrographic examination show that the spring fracture has two fracture surface patterns. Spring B experienced a brittle fracture where the fracture shape was flatter and did not show residual fracture, as seen in Figure 4. Meanwhile springs A, C and D experienced ductile fracture as seen in Figure 3 - Figure 6 which shows residual fracture in the form of a 45° angle. These two fracture patterns have a fast crack propagation path with no fatigue fracture characteristics.

Figure 3. Fracture surface of spring sample A which experienced ductile fracture

Figure 4. Fracture surface of broken spring sample B which experienced a Brittel fracture

Figure 5. Fracture surface of broken spring sample C which experienced ductile fracture

Figure 6. Fracture surface of a broken spring sample D which experienced ductile fracture.

Other damage found that can be seen visually is in the form of holes on the surface (pitting corrosion), both on broken and unbroken springs. There is thinning (reduction in diameter) on the spring surface due to corrosion attacks spread throughout the spring surface and local corrosion at points where there are deposits.

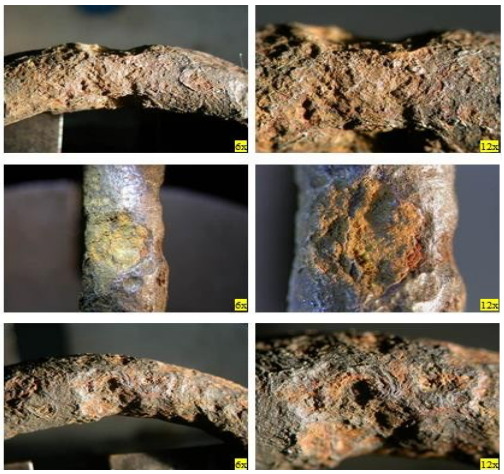

Figure 7. Thinning occurred and several forms of defects were found on the spring surface

The closer to the location of the most critical fracture or thinning, the more corrosion products are found. And conversely, the further away from the location, the fewer corrosion products are found. So it can be concluded that the most critical location of fracture or thinning is the part of the spring that is submerged by fluid entering the spring actuator chamber.

Metallography Examination

Metallographic examination was carried out at 3 locations where spring A was broken, namely: the fracture surface in longitudinal section (location 1), the intact spring in cross section (location 2) and the corroded spring in cross section (location 3).

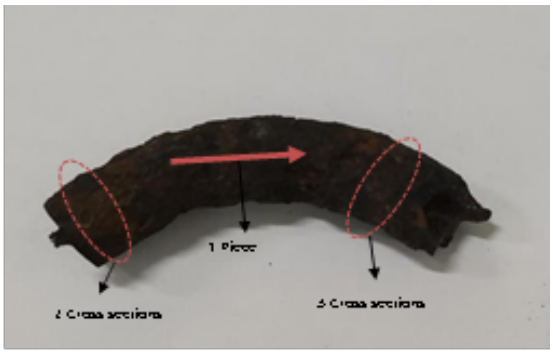

Figure 8. Location of Cutting Direction for Metallographic Sample Sample A

Figure 9. Location of Etched and Non-Etched Metallographic Examination of Spring Sample A

At location 1 of the longitudinal cut fracture surface, the defect hole on the spring surface has an irregular shape with a depth of 1097.19µm with an image magnification of 6x.

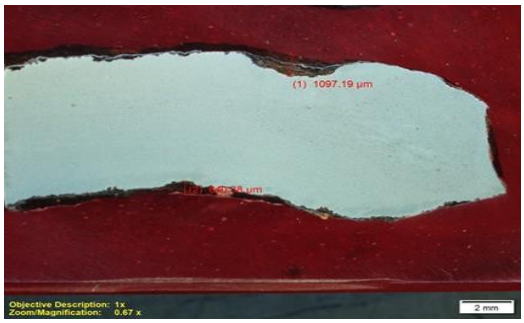

Figure 10. Macro photo of spring etching A fracture surface with a longitudinal cut

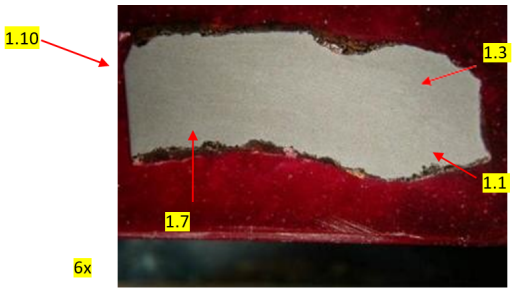

Figure 11 Photometallographic Location of Spring A, Fracture Surface with Longitudinal Sections.

In the non-etching metallographic examination at locations 1.1 and 1.3, corrosion products were found in the spring surface area. There are non-metallic inclusions in the form of sulfides and micro voids.

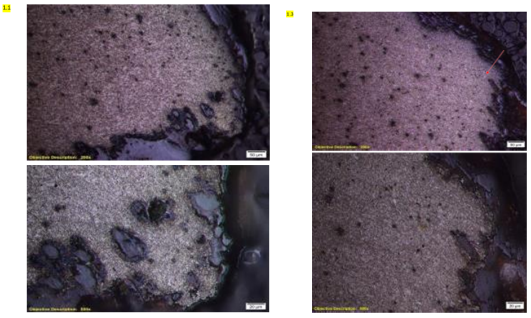

Figure 12. Metallographic examination of etching locations 1.1 and 1.3 with 200x and 500x magnification

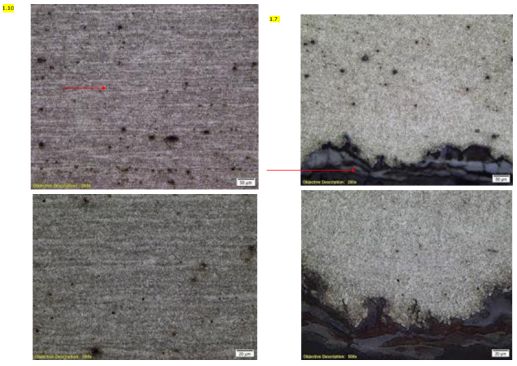

Figure 13. Metallographic examination of etching locations 1.10 and 1.7 with 200x and 500x magnification

From the results of metallographic observations on sample A at location 1, the longitudinal section cuts the microstructure in the form of tempered martensite. Corrosion products were also found in the spring surface area. There are micro voids and inclusions in the form of sulfides. The etching used for this material is 2% nital and the magnification used is with a 200x and 500x magnification lens. At location 2 with an intact surface cross section, the defect hole is semi-circular in shape with the largest depth ±0.193 mm.

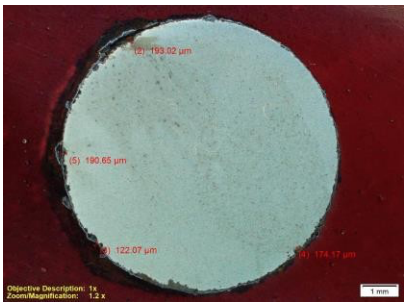

Figure 14 Full Macro Photo of Spring A Etching Location 2

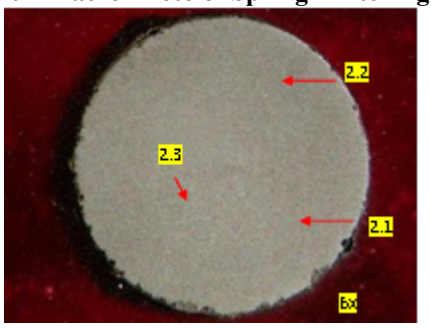

Figure 15 Whole Spring A Metallographic Location with Cross Section at Location 2

Figure 16 Metallographic examination using non-etching location 2.3

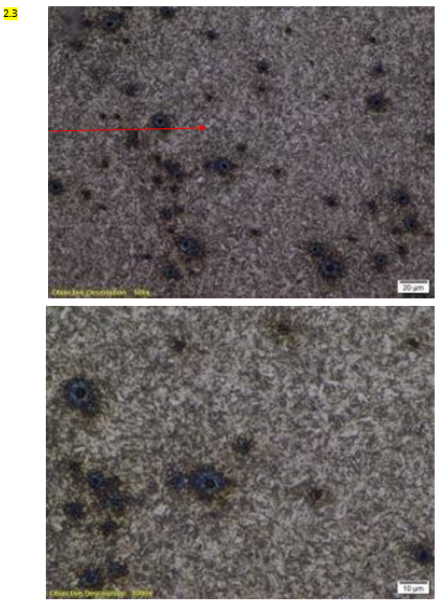

Figure 17 Metallographic examination of location etching 2.3 with 500x and 1000x magnification

From the results of metallographic observations on sample A, location 2 of the transverse direction of the surface is intact, the microstructure is tempered martensite. Corrosion products were also found in the spring surface area. There are micro voids and inclusions in the form of sulfides. No surface hardening was found in the edge area of the spring surface. The etching used for this material is 2% nital and for location 2.3 using 500x and 1000x magnification.

From the results of metallographic observations on sample A, location 2 of the transverse direction of the surface is intact, the microstructure is tempered martensite. Corrosion products were also found in the spring surface area. There are micro voids and inclusions in the form of sulfides. No surface hardening was found in the edge area of the spring surface. The etching used for this material is 2% nital and for location 2.3 using 500x and 1000x magnification

At location 3, with a cross section of the corroded surface, the defect hole is semi-circular in shape with the greatest depth measuring ±1.6 mm.

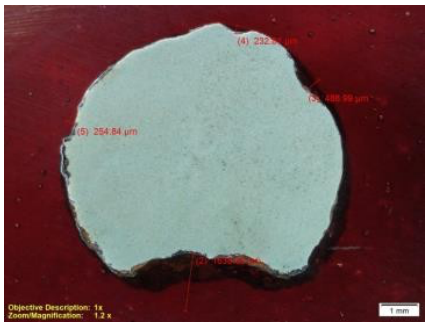

Figure 18 Macro Photo of Corroded Spring A Etching in Cross Section Location 3

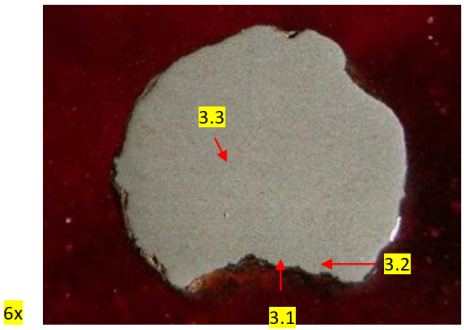

Figure 19 Metallographic Location of Corroded Spring A with Cross Section Location 3

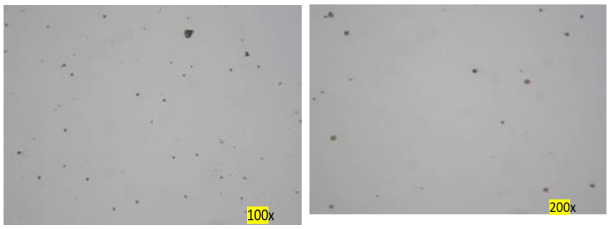

Figure 20 Non-Etching Metallographic Examination Location 3.3

During non-etching metallographic examination at location 3.3, corrosion products were found in the spring surface area. There are non-metallic inclusions in the form of sulfides and micro voids.

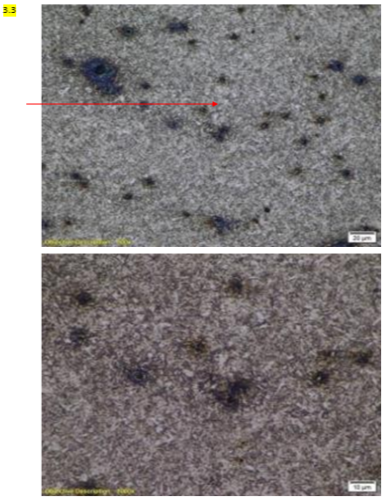

Figure 21 Metallographic examination of location etching 3.3 with 500x and 1000x magnification

From the results of metallographic observations on sample A, location 3 cross-sectional sections of the surface were corroded by a microstructure in the form of tempered martensite. Corrosion products were also found in the spring surface area. There are micro voids and inclusions in the form of sulfides. No surface hardening was found in the edge area of the spring surface. The etching used for this material is 2% nital and for location 3.3 using 500x and 1000x magnification.

Chemical Composition Testing

Table 1 Results of Chemical Composition Examination of broken spring

Element	Elements Content Value (wt%)	JIS G 4801 Grade SUP 12

Fe	REM (Balance)	
C	0.710	0.51-0.59
Si	1.41	1.20-1.60
M N	0.683	0.60-0.90
P	0.0197	≤0.035
S	0.0159	≤0.035
Cr	0.698	0.60-0.90
Mo	0.0067	
Ni	<0.0050	
Al	0.0291	
Co	0.0199	
Cu	<0.0010	
Nb	0.0113	
Ti	0.0069	
V	0.0074	
W	<0.0020	
PB	0.0224	
Sn	0.0066	
B	<0.0001	
Zr	0.0065	
US	<0.0050	
Mrs	<0.0250	

Table 2 Results of Chemical Composition Examination unbroken spring

Element	Elements Content Value (wt%)	JIS G 4801 Grade SUP 12
Fe	REM (Balance)	
C	0.596	0.51-0.59
Si	1.42	1.20-1.60
M N	0.668	0.60-0.90
P	0.0153	≤0.035
S	0.0038	≤0.035
Cr	0.683	0.60-0.90
Mo	<0.0040	
Ni	0.0060	
Al	0.0310	
Co	0.0104	
Cu	0.0030	
Nb	<0.0030	
Ti	0.0031	
V	0.0052	
W	<0.0020	
PB	0.0218	
Sn	0.0078	
B	<0.0001	
Zr	0.0059	
US	<0.0050	
Mrs	<0.0250	

After carrying out chemical composition tests on both broken springs and springs that were not broken, it can be seen in the table above that both spring materials still meet the JIS G 4801 grade SUP 12 standard. The chemical composition test results when compared with JIS G 4801, the spring material is closer to to SUP 12 with the addition of Silicon and Chrome. The addition of Silicon functions as a deoxidizer, while Chrome is provided to increase resistance to wear, heat and corrosion in general. The silicon content in broken springs is 1.41% and in unbroken springs it is 1.42%. The Chrome content in broken springs is 0.698% and in unbroken springs it is 0.683%.

Hardness Testing

Hardness testing was carried out using the Frank Finotest Vickers method with a load of 5 kgf and referring to the SNI 19-0409-1989 standard.

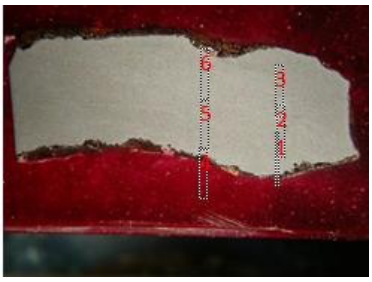

Figure 22 Location of Longitudinal Section Hardness Test for Broken Spring

Table 3 Longitudinal Cut Hardness Test Results Broken Spring

No	Hardness Value (HV)
1	515
2	532
3	507
4	500
5	523
6	507
Average	514

The figure above shows the scheme and data collection points for hardness testing on longitudinal cut spring material th at has failed. The hardness test results show that the longitudinal cut broken spring has a hardness value of 514 HV.

Figure 23 Location of Cross-Section Hardness Test of Whole Spring

Table 4 Cross Section Hardness Test Results Broken Spring

No	Hardness Value (HV)
1	532
2	532
3	515
4	523
5	523
Average	525

The image above shows the scheme and data collection points for hardness testing on intact cross-sectional spring material (sample 2) which failed. From the table above it shows that a broken spring in intact cross section has a hardness value of 525 HV.

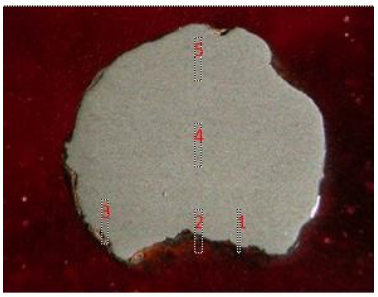

Figure 24 Location of Corroded Spring Cross Section Hardness Test

Table 5 Cross section hardness test results of corroded spring

No	Hardness Value (HV)
1	523
2	507
3	507
4	532
5	523
Rata-rata	518.4

The image above shows the scheme and data collection points for hardness testing on intact cross-sectional spring material (sample 2) which failed. From the table above it shows that a broken spring in intact cross section has a hardness value of 525 HV.The image above shows the scheme and data collection points for hardness testing The picture above shows the scheme and data collection points for hardness testing on a corroded cross-sectional material spring (sample 3) which failed. The hardness test results show that the corroded cross-sectional broken spring has a hardness value of 518.4 HV.

Overall, the spring hardness value is above the maximum hardness limit for SUP 12 material. In JIS G 4801 grade SUP 12 material, the maximum hardness limit is 450 HV. This occurs due to the heat treatment process in spring manufacturing.

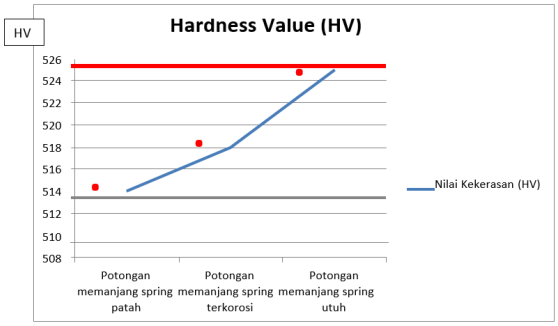

Figure 25 Graph of hardness value (HV) results

From the graph of the results of the hardness values above, from intact spring pieces to broken springs, there is a decrease in the hardness value, this is caused by a corrosion attack on the spring.

Scanning Electron Microscope (SEM) EDX analysis

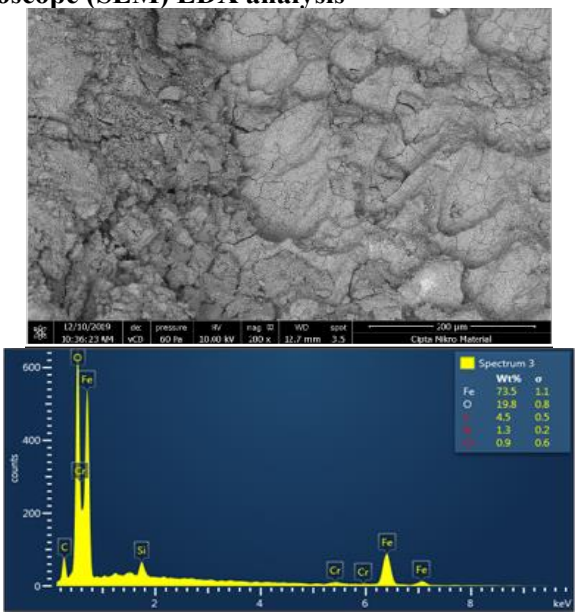

Table 6 SEM-EDAX Results of Fracture Surface *Spring*A

Elements	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %	Standard Label
C	2.52	0.02524	4.53	0.51	12.61	C Vit
O	64.45	0.21689	19.75	0.80	41.26	SiO2
Si	1.85	0.01466	1.30	0.18	1.55	SiO2
S	0.36	0.00307	0.24	0.10	0.19	FeS2
Cr	1.29	0.01294	0.91	0.59	0.58	Cr
Fe	90.23	0.90225	73.51	1.11	44.00	Fe
Total:			100.00		100.00	

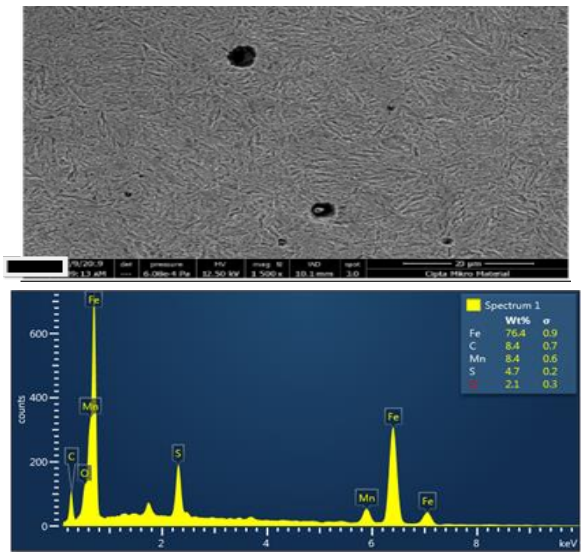

Table 7 SEM-EDAX Results of Fracture Surfaces of Spring A Metallographic Samples

Elements	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %	Standard Label
C	2.23	0.02226	8.36	0.66	27.86	C Vit

O	3.80	0.01280	2.14	0.32	5.37	SiO2
S	4.90	0.04223	4.71	0.23	5.88	FeS2
M N	7.60	0.07601	8.35	0.63	6.09	M N
Fe	70.77	0.70769	76.44	0.89	54.81	Fe
Total:			100.00		100.00	

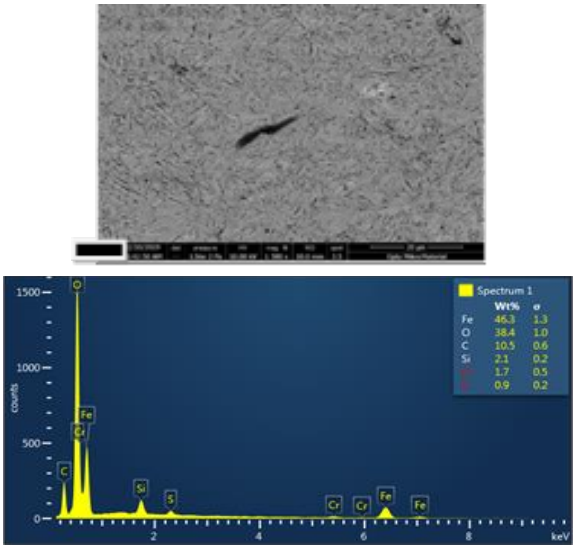

Table 8 SEM-EDAX Results of Hole Defects in Longitudinal Sections of Spring A

Elements	Apparent Concentration	k Ratio	Wt%	Wt% Sigma	Atomic %	Standard Label
C	6.06	0.06060	10.51	0.56	20.63	C Vit
O	111.26	0.37440	38.39	1.00	56.57	SiO2
Si	2.82	0.02235	2.09	0.17	1.75	SiO2
S	1.26	0.01085	0.92	0.15	0.68	FeS2
Cr	2.12	0.02125	1.74	0.50	0.79	Cr
Fe	50.02	0.50022	46.35	1.30	19.57	Fe
Total:			100.00		100.00	

SEM test results of spring samples show the presence of non-metallic inclusions with an elongated morphology and micro-sized voids. Meanwhile, the EDX test results showed that there was a sulfur content of 4.71 wt% in non-metallic inclusions and Fe and O elements in defect holes which were corrosion products.

Results

Material Defects

The results of the metallographic examination showed that there were inclusions and micro voids which could be seen both etched and non-etched (Figure 4.9 - Figure 4.29) which were then confirmed by the SEM-EDX test (Figure 4.34 - Figure 4.36). Inclusions come from the base metal in the spring manufacturing process. From the results of the chemical composition test, there are Mn and S elements. The addition of manganese (Mn) anticipates oxidation and the formation of Fe bonds with S in the form of iron sulfide (FeS) which has a lower melting point than Fe. Sulfur (S) is an element that tends to be considered an impurity, but in small amounts (<0.05%) it has a positive effect, such as making steel easy to shape. The S element must be kept as low as possible because it will later bind with manganese to

form unwanted manganese sulfide (MnS) inclusions.

From the SEM test results, sulfide inclusions were spread throughout all areas of the test sample with varying sizes and elongated flat morphology (Figure 4.36). From the EDX test results, the spectrum of elements contained in the inclusions is Mn and S. The elements Mn and S appear dominant, thus strengthening the suspicion that there are MnS inclusions. MnS inclusions have the potential to be the start of micro-scale cracks because these inclusions are places of stress concentration (stress raisers) and the weakest part of the matrix material. Micro voids are empty cavities found in the spring. These cavities originate from non-metallic inclusions formed during the hot working process during manufacturing. These micro voids have varied shapes and are distributed with the majority being in the core area of the spring.

Corrosive Environment

The triggering factors for corrosion in this case are muddy fluid and air entering the spring actuator chamber. Poor packing is one of the causes of fluid and air entering the chamber and then soaking the body of the spring. The movement of the spring is fully bump and fully rebound. The presence of fluid in the chamber has the potential to create a splash zone. The splash zone is a part of the material that is periodically exposed to fluid, causing the spring surface to become wet and dry. The splash zone has an area of vertical distance between the upper splash zone and the lower splash zone.

The fluid and mud in the spring chamber stick as deposits in the splash zone area which is caused by the movement of the spring when it fully bumps and fully rebounds. The mud that sticks to it becomes a deposit and is left for a long time so that a corrosion reaction occurs and causes corrosion. From the explanation of the factors above, the main factor causing spring damage is the corrosion process caused by unwanted fluid entering the spring chamber which is then supported by manufacturing process errors which produce inclusions and micro voids, so that the damage process becomes faster. Springs that are exposed to corrosion attack form holes resulting in thinning or reduction in the size of the spring. This results in an increase in stress concentration in the spring area which is thinning and reduces the strength of the spring in withstanding the valve's operational load in the form of dynamic compressive load. The combination of these 3 factors causes the spring to break in the area experiencing the most critical thinning so that the valve does not fully close.

CONCLUSION

Based on the results of the examination and discussion, it was concluded that the cause of damage to the spring actuator was the entry of unwanted corrosive fluid into the spring chamber, causing a corrosion reaction to occur. The shot peening process is not carried out in the spring manufacturing process which results in a lack of spring resistance to dynamic loads, the tempering process is not carried out perfectly (Imperfect Tempering) so that the spring is brittle which is sensitive to dynamic loads (Decreased ductility). From the SEM test results, sulfide inclusions were spread throughout all areas of the test sample with varying sizes and elongated flat morphology. From the EDX test results, the spectrum of elements contained in the inclusions is Mn and S. The elements Mn and S appear to be dominant with a sulfur content of 4.71 wt% in the non-metal inclusions. so that there are MnS inclusions. MnS inclusions have the potential to be the start of micro-scale cracks because these inclusions are places of stress concentration (stress raisers) and the weakest part of the matrix material. The type of corrosion that occurs is localized corrosion which is initiated due to deposits attached

to the surface of the spring and only occurs in certain locations (for example: metal surfaces under the deposit). Based on the results of all tests carried out and taking into account various environmental factors that exist in the operation, the factors causing damage are material defects and corrosive environments, to prevent failure/damage to the spring actuator, this can be done by repairing the spring actuator chamber packing properly to minimize fluid entry into the chamber, carrying out routine valve unit maintenance. in accordance with the correct SOP, and carry out post-purchase spring material quality checks from the manufacturer so that they comply with the standards of the material to be used.

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