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Review Article

Effect of Elevated Temperature and High Vibration on Centrifugal Gas Pump Separator of Oil Mine Submerged in Salt Water

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Abstract

A centrifugal gas pump in oil mine was used at elevated temperature and sour environment. The pump was submerged in water to certain height. The body of the pump was ductile cast iron containing 9wt% Ni. The ductile cast iron microstructure of pump body at the top contains Chunky graphite. The lower part of the pump contains spheroidal graphite. The pump was subjected to vibration and salts of the sea in addition to heat. The heat reduced the graphite size (Chunky type) of the upper part of the pump while the lower part of the pump (base) was submerged in water which prevented the reducing of graphites (spheroidal type). The effect of salts on the upper part of Chunky graphite plus the vibration created connected caves and severe crack initiators. The cracks during vibration propagated in the upper part forming severe cracks net in matrix, graphites and carbides. The heat induced aging phenomena to increase the hardness of the upper part of pump.
Keyword: Centrifugal gas pump separator, Oil mine, Elevated temperature, High vibration, ductile cast iron containing high Ni, Catastrophic cracks, Aging phenomena.

INTRODUCTION

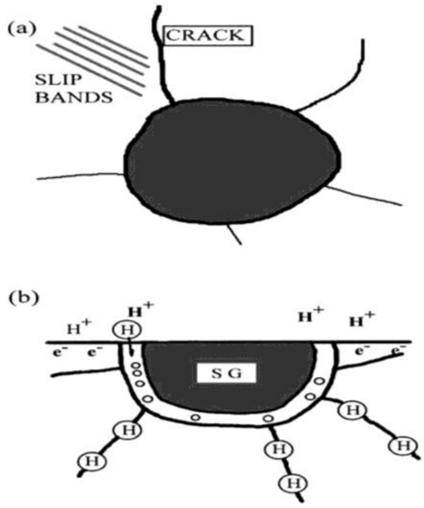
Failures of machine elements in Petroleum sites are very common due to several reasons such as Hydrogen Embrittlement, Aging Phenomena or Stress Corrosion Cracking during mechanical vibration. The proper properties of the materials used in petroleum site are so critical and sensitive to fulfill the needed requirement specification.

Hydrogen Embrittlement

Embrittlement may occur in many metals in presence of a very small amount of hydrogen. Hydrogen may be introduced during melting and entrapped during solidification, picked-up during solid state processing or introduced during corrosion process. Hydrogen is present in the metal as monoatomic hydrogen due to the dissociation of molecular hydrogen by chemisorption at the surface or as a result of oxidation reaction. Hydrogen causes delayed fracture at a stress level significantly lower than the strength of the metal. The fracture process may be cleavage, intergranular or transgranular and no single fracture mode is characteristic of hydrogen embrittlement. There is no univocal mechanism for hydrogen embrittlement; the description of the hydrogen – metal interaction mechanisms can be found elsewhere [1, 2].

Stress-Corrosion Cracking (SCC)

Stress-corrosion cracking is the failure of an alloy from the combined effects of a corrosive environment and a static tensile stress [2, 3]. The chemical environment causing SCC does not produce chemical corrosion of the alloy and the species causing SCC need not be present in large concentration. The formation and rupture of a passive layer at the crack tip is an important mechanism. Moreover, it is widely believed that electrochemical dissolution plays a major role in the crack initiation and propagation. There is a possibility of the adsorption of damaging ions that weaken the atomic bonding at the crack tip. If hydrogen is generated as a result of corrosion species, it is then able to enter the metal, diffuse to the crack tip and cause crack propagation.



(a) The preferred crack initiated sites and slip bands are mainly in the vicinity of graphite nodule.

(b) The absorption of atomic hydrogen along metal matrix grain boundaries and the Graphite vicinity.

Fig-1: Hydrogen attack and crack initiation

Artificial Aging

Artificial aging is heat treatment of metal at elevated temperature which accelerate the changes in the properties of metal as a result of casting or processing such as hot rolling or forging process. The chemical compositions of metals naturally change very slowly at room temperature while artificial aging accelerates this change more rapidly at higher temperatures. This process ensures quality and accuracy in close tolerance specifications. Artificial aging increases strength at the expense of elongation. Therefore, the machine part would early fail.

Received Failed Part

Centrifugal oil lift pump was received the as shown in Fig-2. It is apparent that the upper part is failed due to unknown several reasons. Therefore it is necessary to analyze the material to determine the reasons behind the failure.

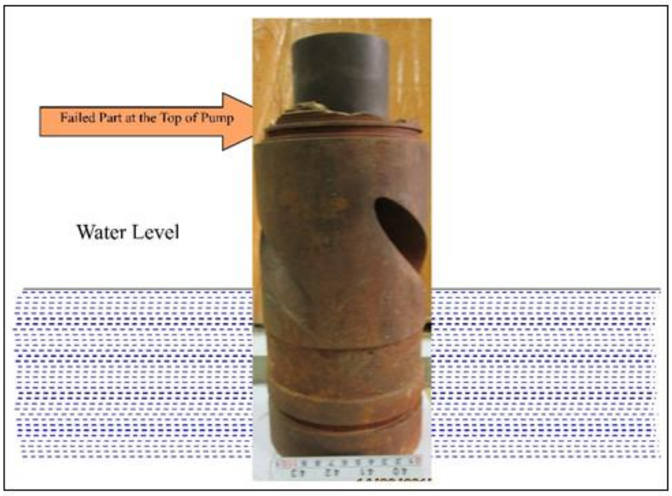


Fig-2: The as-received centrifugal Lift gas separator

The chemical composition of the outer body is demonstrated in Table-1.

Table-1: Chemical Composition, wt%

C	Si	Mn	P	S	Cr	Ni	Mo	Ti	V
3.11	3.36	0.75	0.009	0.035	2.34	15.17	0.064	0.009	0.042

It is clear that the material of the outer body (failed body) of the pump is ductile cast iron containing high nickel.

ANALYSIS AND DISCUSSIONS

Optical Microstructure

Figures 3, 4 and 5 show the crack accommodation with graphite, matrix and carbides. Figure-3 demonstrates the path of cracks starting from the broken edge at the top of pump. Figure-4 shows micro cracks starting from graphite and spread in the matrix.

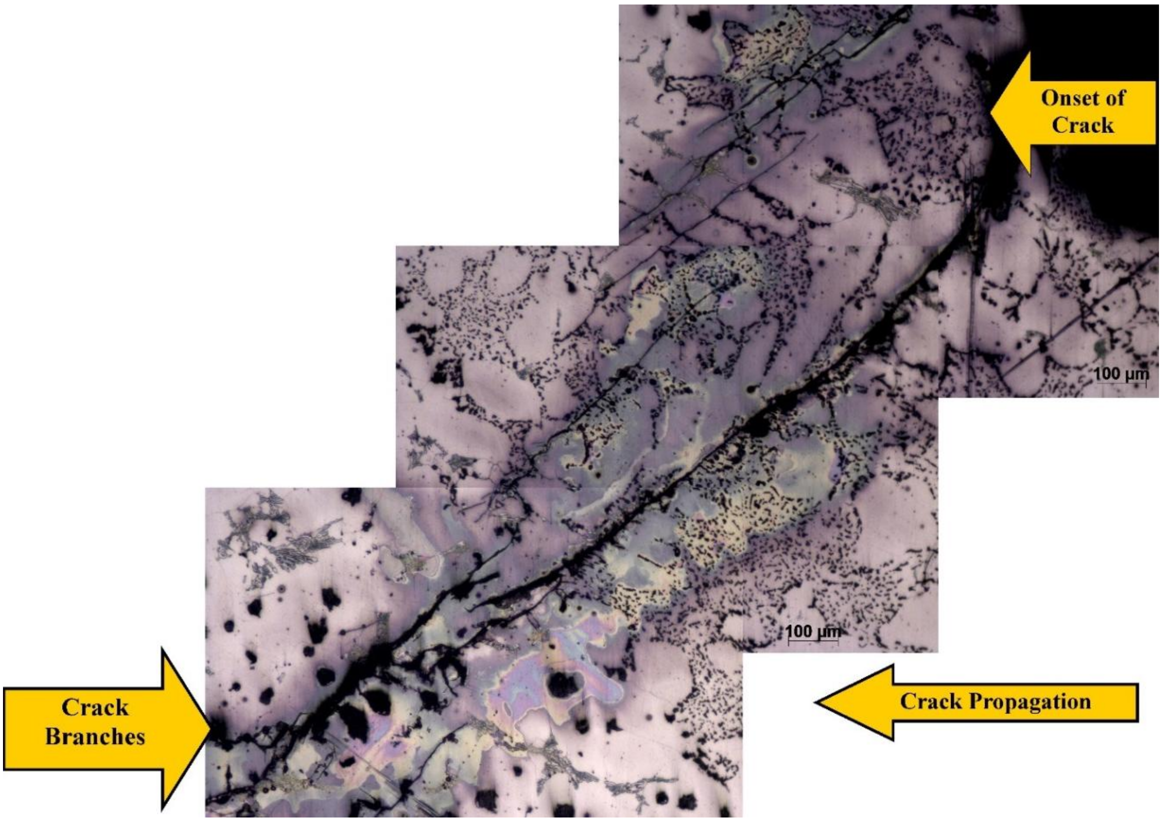


Fig-3: General view demonstrating the cracks started from the Chunky graphite at the edge coinciding with the matrix

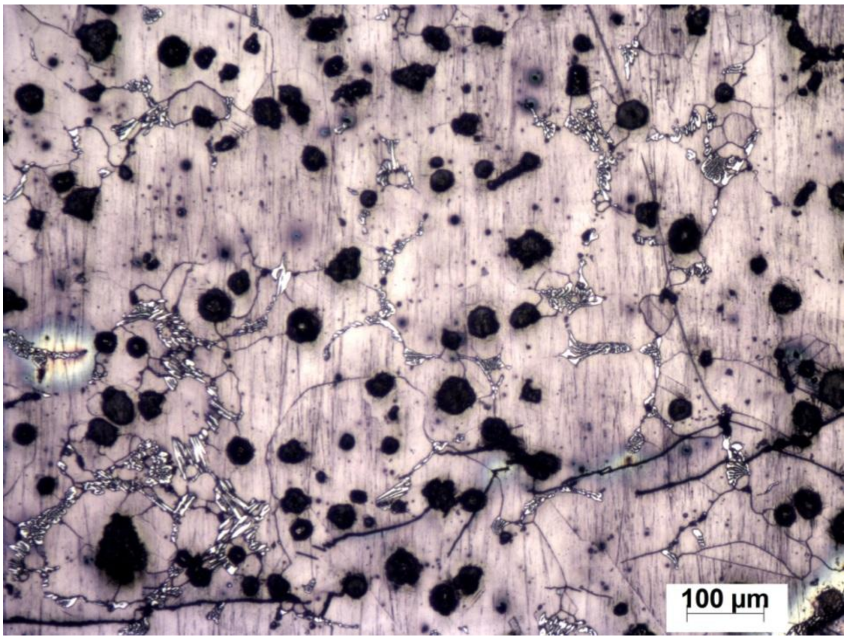


Fig-4: Transgranular crack coinciding with the metal matrix, graphite and carbides due to vibration

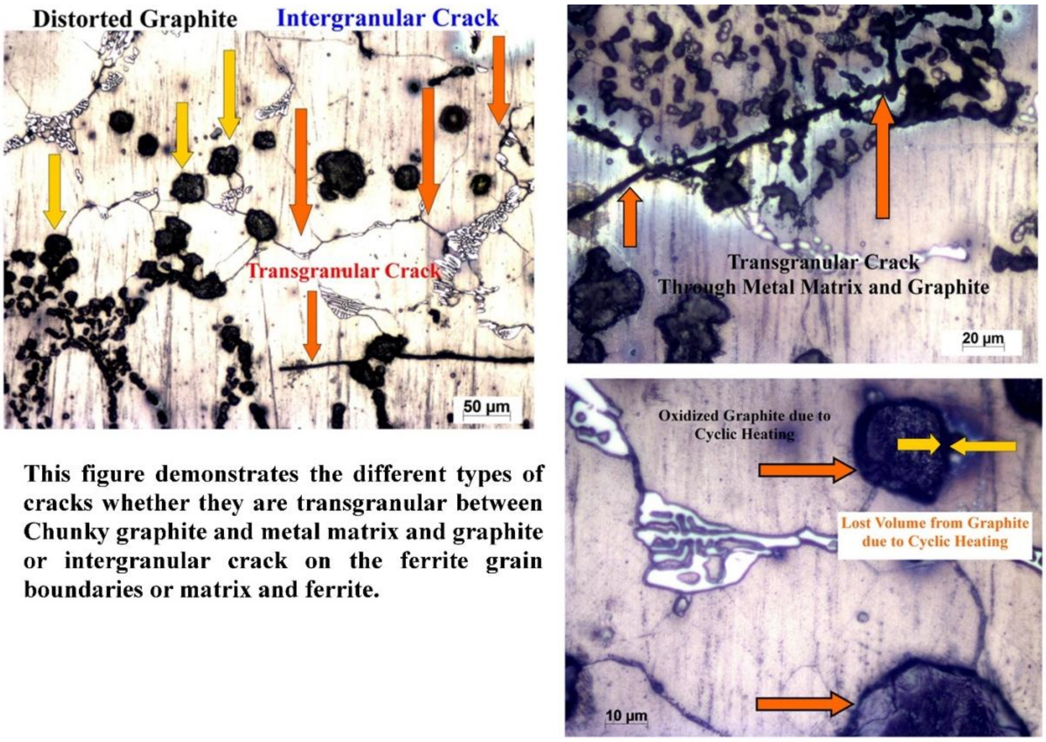


Fig-5: General view of optical microstructure showing the path of cracks through the graphite and matrix, also the graphite shapes after distortion due to heat and oxidation as well as segregated carbides on the cracks type transgranular or intergranular

Figure-6 is the SEM microstructure of the edge of the upper part of the failed body for pump. It exhibits the graphite of Chunky type (fine carbides) inside the cast iron matrix. However, it is clear that the graphite is decreased in its volume due to pump circumstances (heat and vibration). This failure was because pump was working at elevated temperature and vibration without cooling of water which leads to oxidation of graphite).

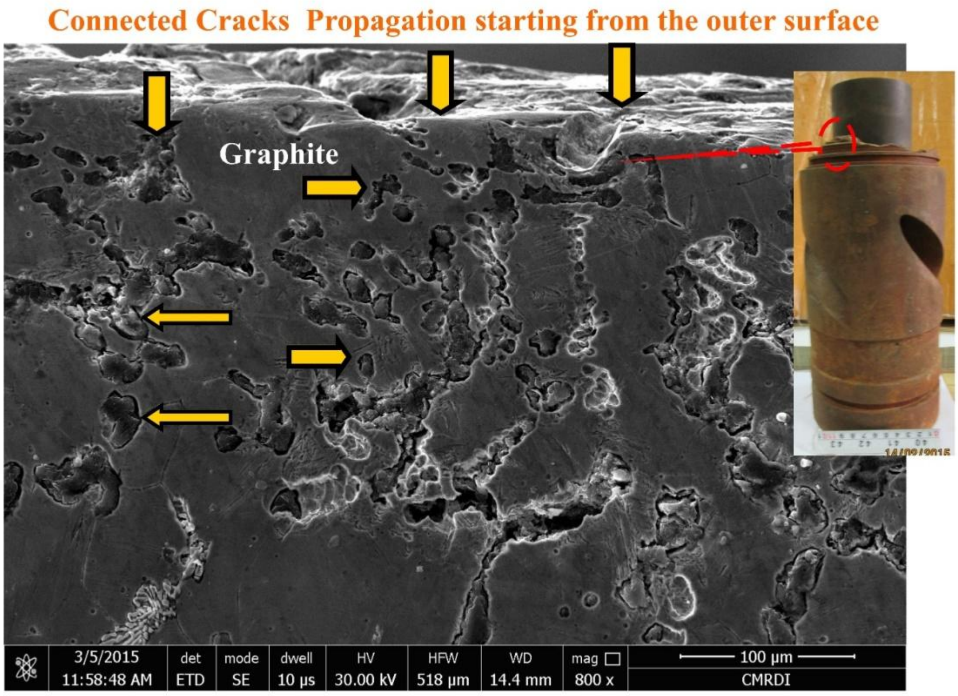


Fig-6: General view of the outer surface and cross-sectional area demonstrating the fatigue after several cyclic heating

Figure-6 shows the graphite of the outer surface of the oil pump at high magnification. It is apparent that the oxidation decreases the graphite size and made the metal matrix like connected caves. Figure-6 also demonstrates the existence of slip bands due vibration which highly decreases the fatigue life of the body and they are catastrophic source for crack initiation. It is also noticed that the slip bands of deformation are located near the graphite in the ductile matrix [4]. Figure-7 shows the mode of crack propagation with graphite, segregated carbides and metal matrix. Figure-8 clarifies the details of cracks where they prefer to connect between two pieces of graphite through the metal matrix. Figure-7 illustrates the catastrophic cracks due to vibration at elevated temperature starting from the outer surface to the body interior.

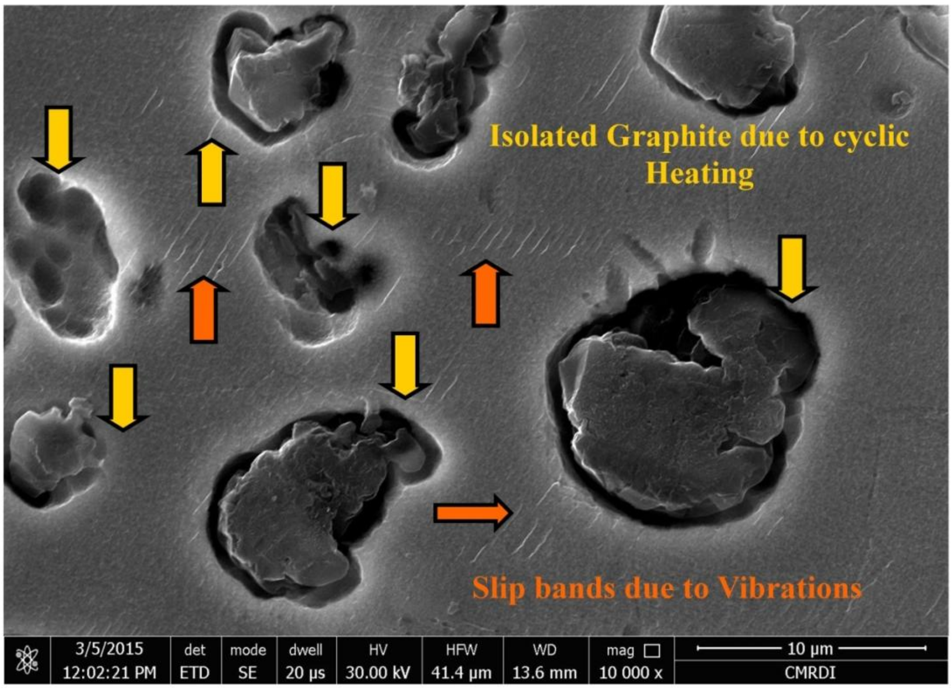


Fig-7: Details of graphite showing the slip bands

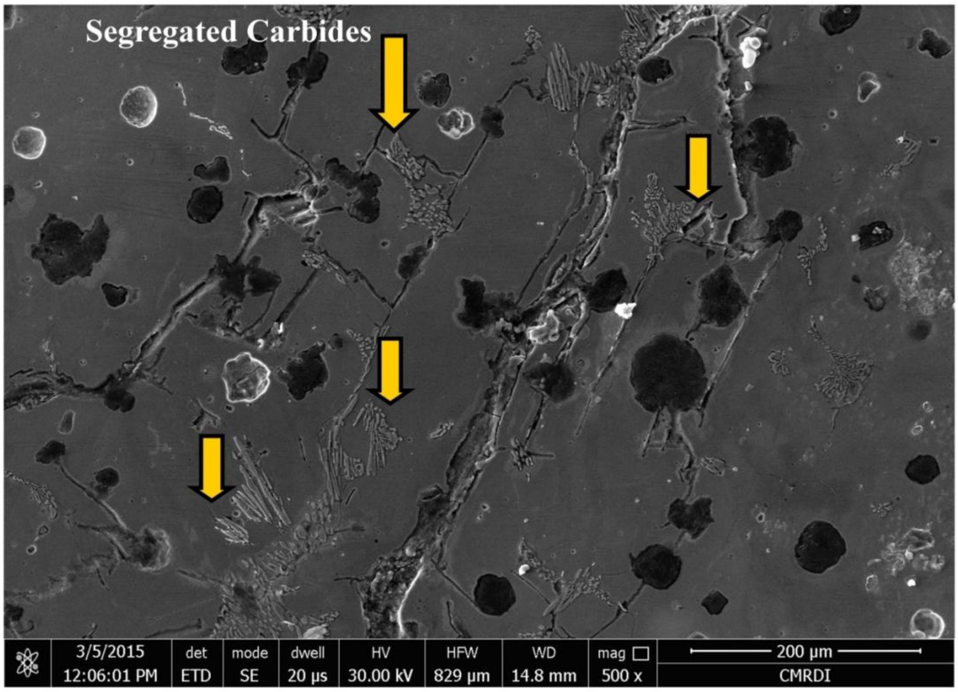


Fig-8: General view of different cracks, graphite and carbides segregated

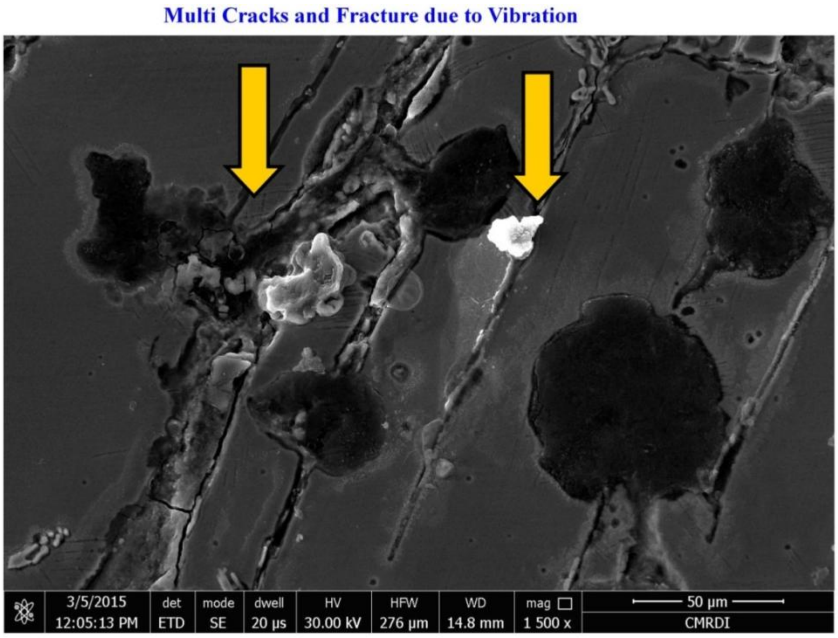


Fig-9: Details of different cracks passing through the matrix and graphite contaminated with chemicals

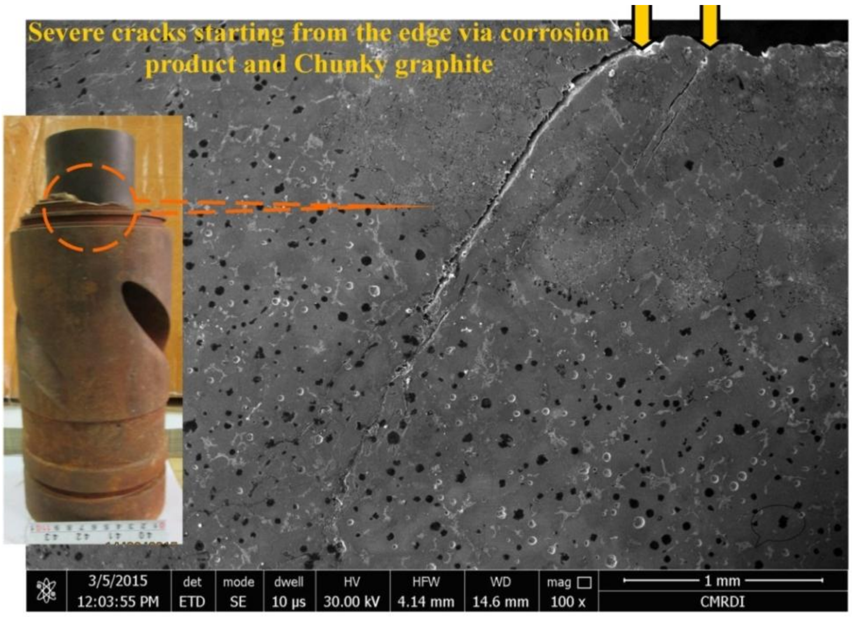


Fig-10: Catastrophic cracks due to vibration at elevated temperature starting from the upper part surface

Fig-11 is a general view of the chemical product of failed surface. Fig-12 demonstrates at relatively high magnification the crystals of salts attacking the surface of material. Fig-13 show a general view of the corroded surface while Fig-14 shows the chemical product which is embedded into crack of the upper surface of failure or side wall. Fig-15 emphasizes the existence of salt crystal. Fig-16 illustrates the chemical product on the surface of failure, it is clear that the surface was subjected to sodium chloride due to using hard water of high salinity. It also demonstrates that the surface was at elevated temperature producing two types of iron carbides. Fig-17 provides the different phases of the corrosion products. It is apparent that the cast iron material used in this pump is austenitic one. Furthermore, it proves that the material was attached by hydrogen forming iron hydroxide. Table-2 and Fig-18 provide the hardness distribution on the failed surface. It is clear that the average hardness is 326Hv. On the other hand, the lower part of the pump (base) shows the hardness distribution of the pump surface in Table-3 and Fig-19. The average hardness of the lower base of the pump is 174Hv. This difference of hardness of one body of the pump is due to submerging of the lower part in water which cooled the base of the pump and prevented the aging process and the distortion of the graphite. While the upper part (failed) was without water therefore the aging process affected graphite and increased the hardness due to carbon diffusion.

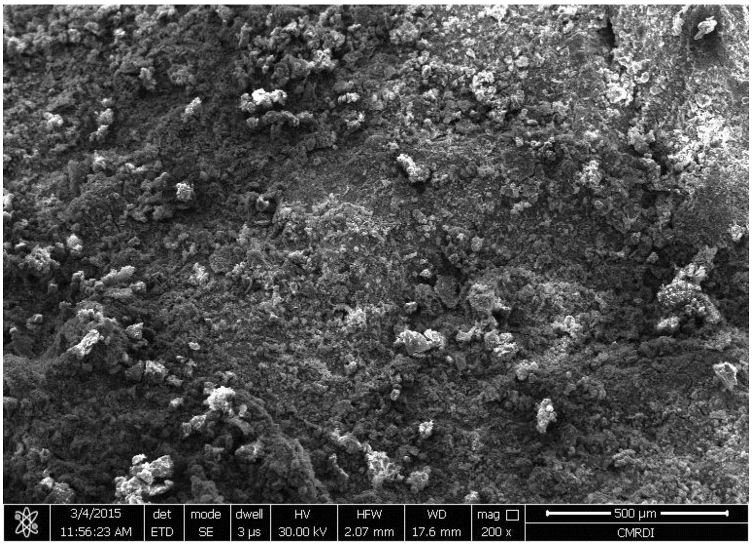


Fig-11: General view of the cracked surface of the body of the pump showing the chemical product on the corroded surface

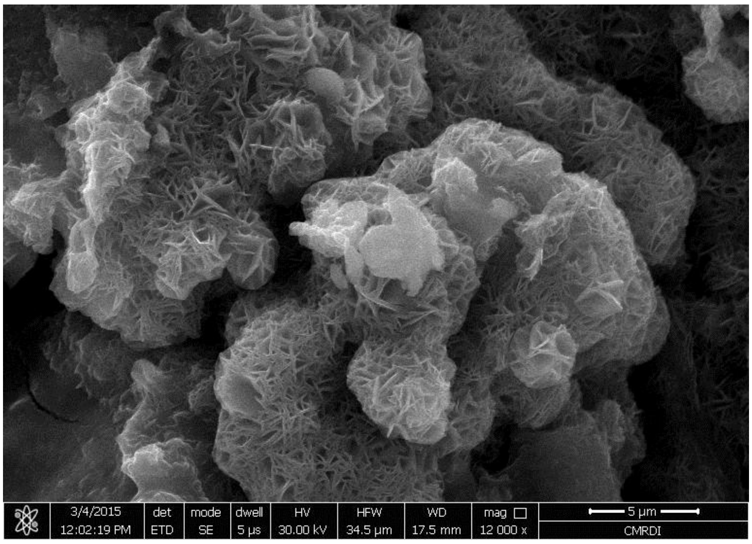


Fig-12: Corroded surface details demonstrating the crystals of salts

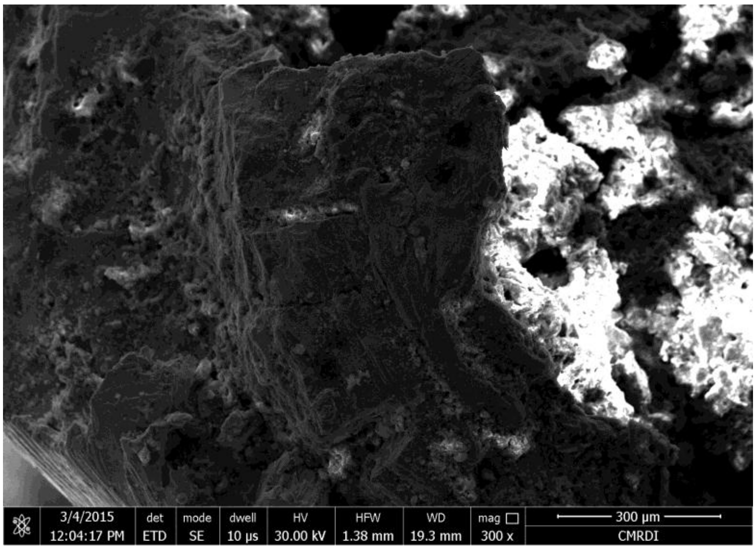


Fig-13: General view of the chemical attack on the fracture surface

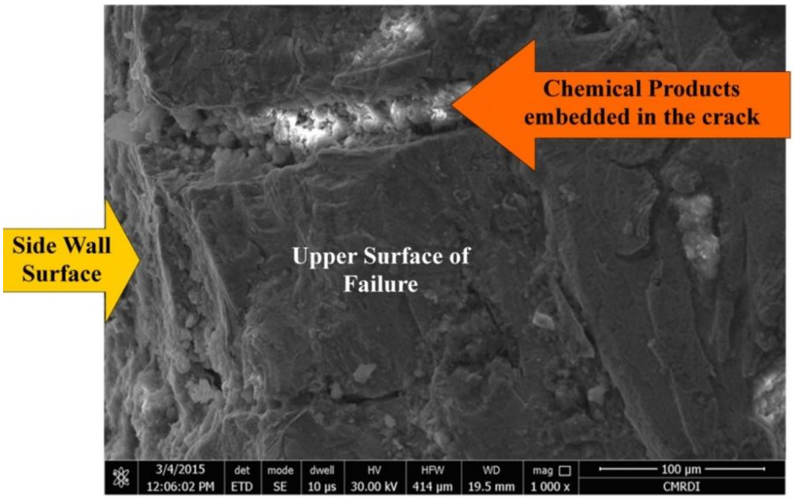


Fig-14: Fracture surface corroded and the chemicals penetrated through the cracks

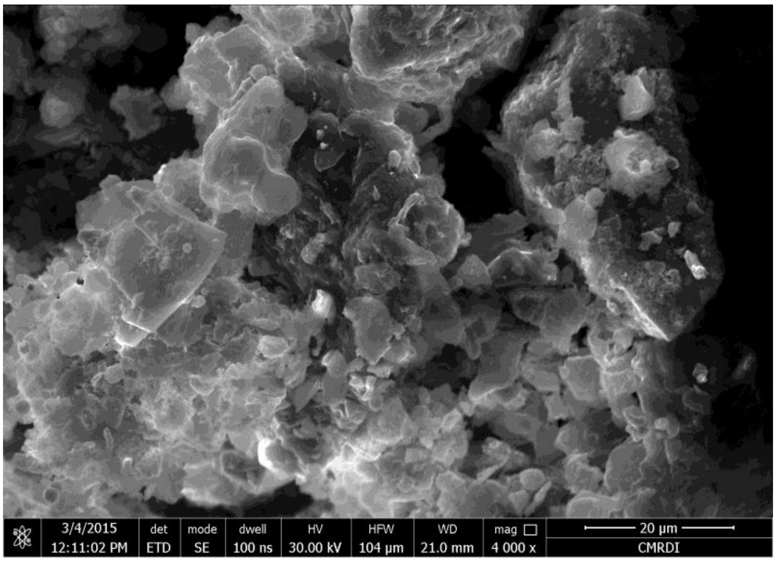


Fig-15: Showing the crystals of the chemicals attacking the fracture surface

X-Ray Detection

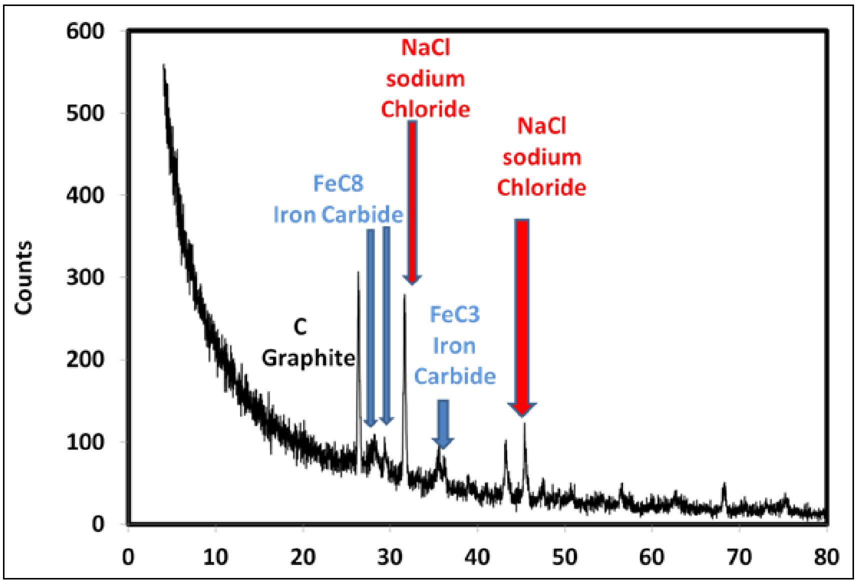


Fig-16: X-ray diffraction of chemical compound attached the fracture surface

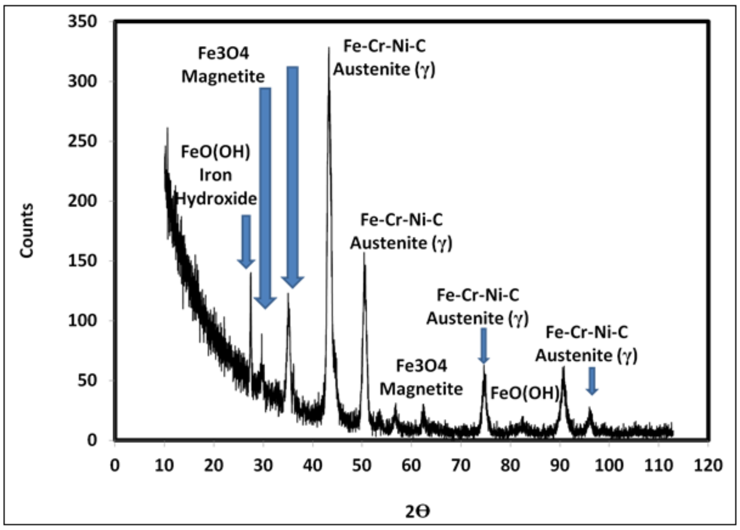


Fig.17 X-ray diffraction of different phases

Hardness of the Upper failed part

Table-2: Hardness for failed part of the body

Hardness, HV 20kg of failed pat	
Mean	323.6
Standard Error	4.3
Median	322.5
Mode	316.0
Standard Deviation	16.0
Sample Variance	256.2
Kurtosis	0.3
Skewness	-0.8
Range	53.0
Minimum	289.0
Maximum	342.0
Confidence Level (95.0%)	9.2

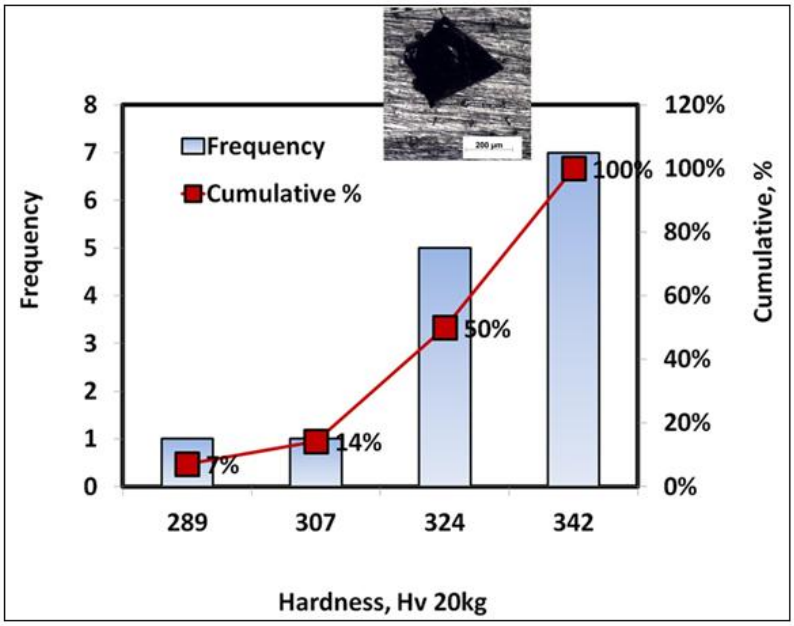


Fig-18: Hardness distribution of failed upper part

Table-3: Hardness of the lower base

Hardness of the base	
Mean	174
Standard Error	1
Median	174
Mode	-----
Standard Deviation	2
Sample Variance	6
Kurtosis	-1
Skewness	0
Range	7
Minimum	170
Maximum	177
Count	8
Confidence Level (95.0%)	2

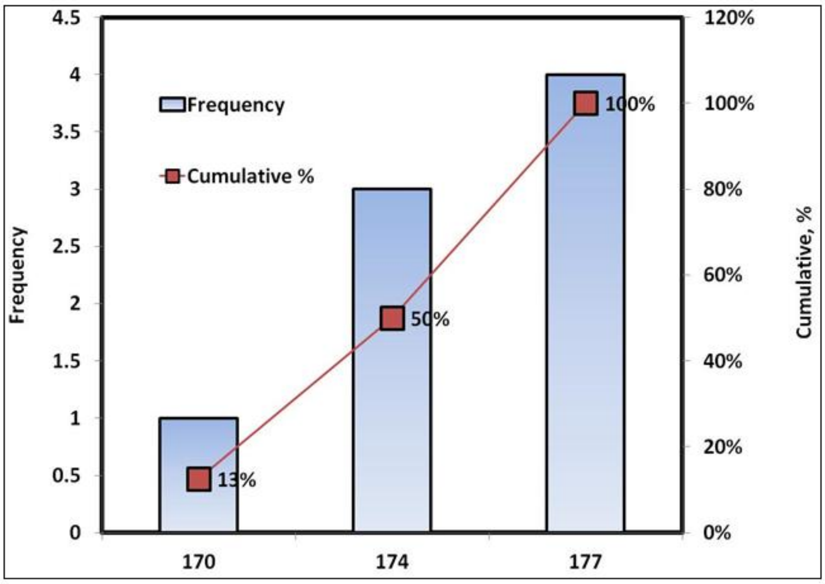


Fig-19: Hardness distribution of the base metal

Figures 20, 21, 22 and 23 show that the graphite of the base of the pump is sound without any distortion in graphite shapes. This emphasizes that the metal of the pump base was submerged in water preventing the aging phenomena to happen and the graphite distortion to occur.

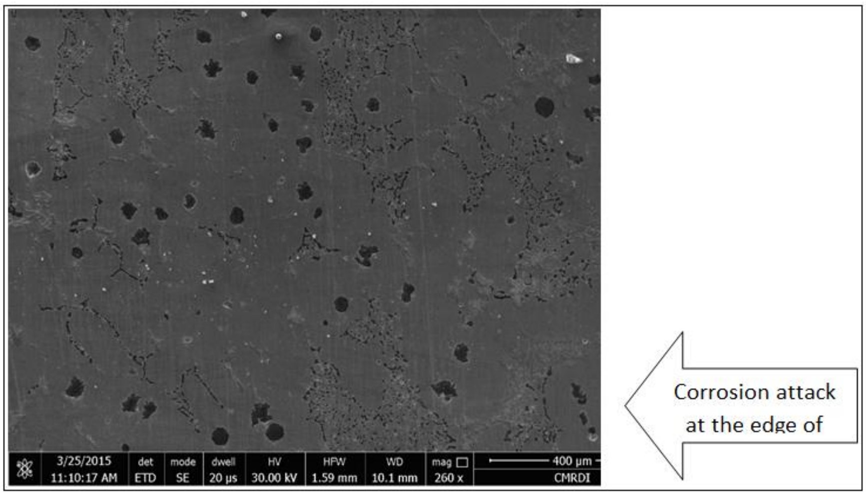


Fig-20: General view of the graphite of the base of the pump (submerged in salty water)

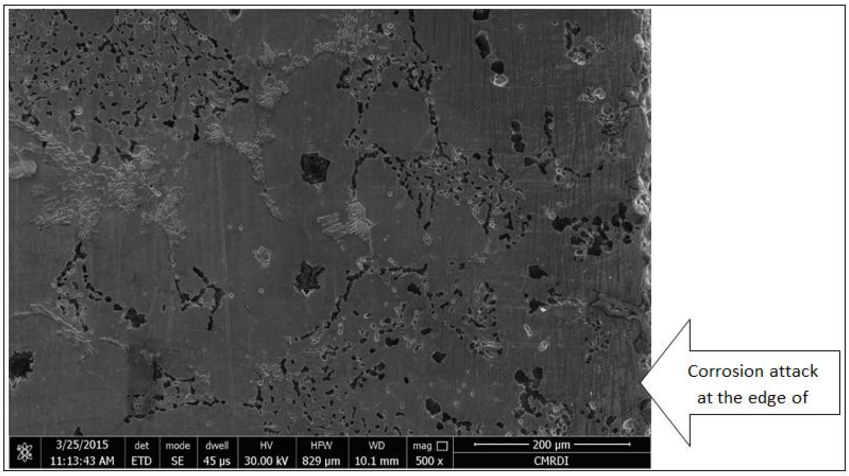


Fig-21: General view of the graphite of the base of the pump (submerged in salty water) at different zone

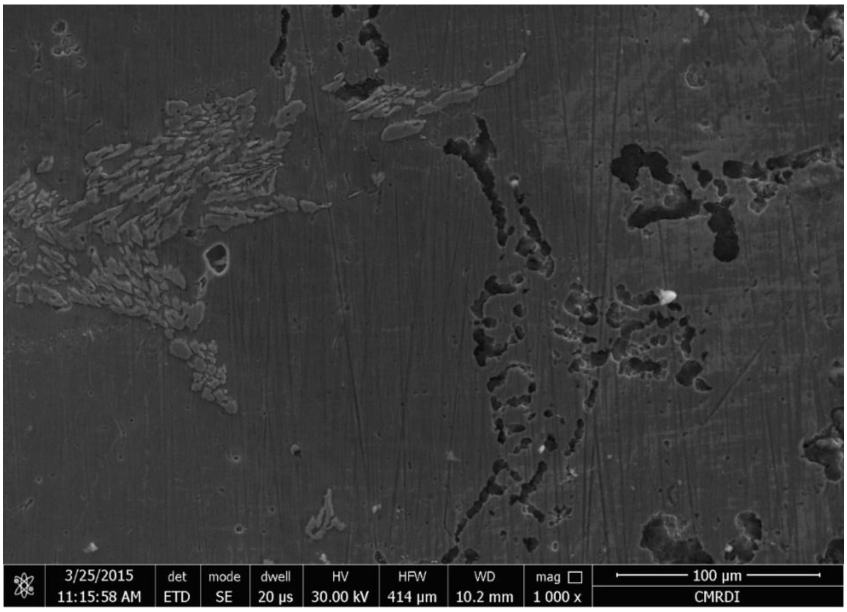


Fig-22: View of Chunky graphite showing sound graphite

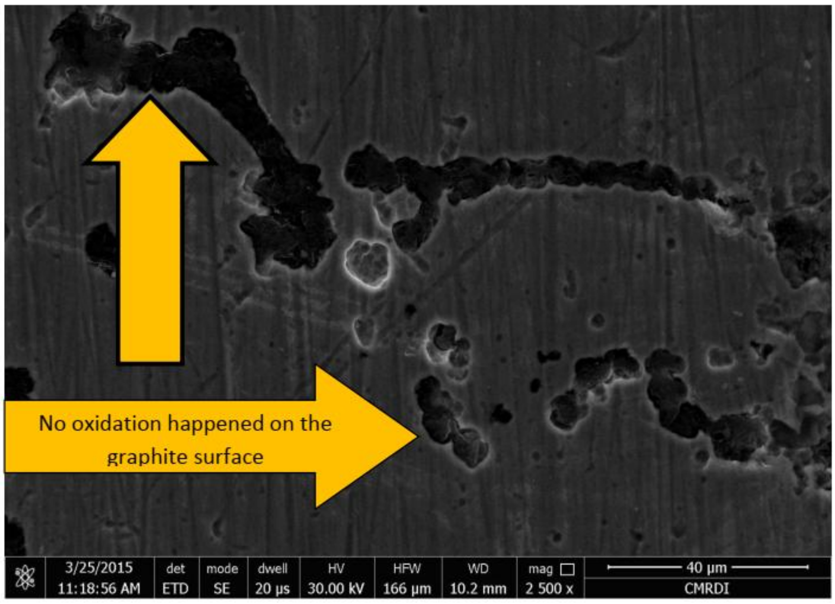


Fig-23: Showing the Chunky graphite at relatively high magnification

CONCLUSIONS

The outer body of the lift body is manufactured from high Ni ductile cast iron. It is non-magnetic body.

- This outer body of the lift pump was subjected to cyclic heating, chemical attack and vibration simultaneously. The cyclic heating deteriorated the graphite shapes of the upper part and oxidized them and reduced their volume and consequently allowed to the dangerous chemical compound to attack the metal matrix.
- Due to vibration, the body of the oil pump was under severe environment working quickly creating many sites of crack initiation in the outer body and propagated into inside to attack the whole body creating many catastrophic cracks.
- The oxidation process with vibration converted the metal matrix into caves coincided with cracks which attacked with chemicals.

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