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Evaluation of the Impact of Surface Treatment on the Turbine Blade Performance

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Abstract

The combination of a hard surface and a soft interior is greatly valued in modern engineering because it can withstand very high stress and fatigue, a property that is required in such items as gears, turbine blade and anti-friction bearings. Surface-hardened steel is also valued for its low cost and superior flexibility in manufacturing. This study looked at how the carbonization temp affected the resistance against wear and hardness of the steel alloy utilized to make turbine impellers. The specimens were activated in Co_2 at each temperature for soaking at about 30, 60, 90, and 120 minutes. The carbonization temp was changed from 850, 900, and 950 to 1000C°. The Carburized steels are put through various tests, including wear tests utilizing a pin on a desk, hardness tests utilizing a Brinell-hardness tester, and phase observations utilizing an EDX (Energy Dispersive X- Ray). The findings demonstrated that all carburizing temps improved resistance against wear, and the wear rate decreased with rising temp and prolonged immersion in the carburized medium, minimum wear rate founded at $1000C^0$ for 2hr as soaking time. Additionally, hardness exhibited the same upward trend in resistance against wear as temp and time and maximum hardness recorded at 1000C for soaking time of 2hr was 106BHN compared with plain material 56BHN. EDX analysis demonstrates that the carburizing process for all treated specimens creates an extra carbon phase.

Keywords: Carburizing, Resistance against wear, EDX, Turbine impeller, Hardened steel.

1. Introduction

An experimental investigation is necessary for a complicated process like impeller surface erosion [1-3]. The low-pressure operating environment at a steam turbine engine's exhaust (also called the penultimate stage or last stage) encourages phase change, resulting in the steam condensation into minute water drops. Once created, the water droplets travel with the flow and, following subsequent impacts with the turbine impeller, some of them might strike the blade surface with a velocity above 200 m/s [5-7]. Thus, the significance of surface treatments depending on ancient and contemporary technology has grown. Carburizing, also called carburization, is a heat-remediation method that produces a hard external shell (case) with high resistance against wear by changing the surface composition of low-carbon steel by carbon diffusion. Engineering materials utilizing surface treatments have been demonstrated to enhance corrosion resistance, reduce friction coefficients, and boost resistance against wear [8-9]. By employing several media to study the resistance against wear of low-carbon steel pack carburizing, Kharia S.H. demonstrated that all carburizing compounds increased the steel's resistance against wear and hardness [10]. The improvement in resistance against wear and hardness following carburization and its impact on the microstructure that provides steel-improved surface qualities were validated by M.N. Hawas et al. [11]. Juejun Katesa et al. investigated the impact of the carbonization temp on the porous characteristics. They discovered that rising temp and lengthening the duration for soaking in carburized medium produced activated carbon with the largest BET surface area and lowest pore volume [12]. R. Chotborsk investigated how heat remediation affected the abrasive resistance against wear, hardness, and microstructure. The study's findings revealed that the temp of the destabilization heating remediation and the air and furnace cooling conditions impacted the abrasive resistance against wear, fracture toughness, and hardness [13] A. Z et al. looked at how heat remediation affected a gray cast iron's corrosion and wear behaviors and found that it reduced porosity and roughness while increasing corrosion and resistance against wear [14-15]. Fatai O. investigated the effects of carburizing temperature and time on the mechanical properties of mild steel carburized with activated carbon at 850, 900, and 950 °C, soaked for 15 and 30 minutes at the carburizing temperature, and discovered that the mechanical properties of steels were strongly influenced by the carburizing temperature and soaking time at the carburizing temperature [11]. S.A. Afolalu investigated the effects of carburizing temperature and time variation on cutting tool characteristics and discovered that the carburized tool has a reduced wear rate with time at high carburizing temperatures [16]. Diyar A. Jabbar investigated the effect of the carburizing process on the mechanical properties of low-carbon steel and discovered that carburized specimens have greater wear resistance than untreated samples [17]. Pranjal Kumar Sahu investigates the effects of various

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carburization temperatures and tempering processes on the mechanical properties of carburized mild steel, demonstrating that the value of hardness and tensile strength rises as the carburization temperature increases [18].

The possibility of improving the surface properties of the turbine blade was investigated in this study by performing a surface hardening treatment (carburizing) at different temperatures and for different treatment periods in order to determine the optimum temperature and time needed to achieve maximum improvement of the surface properties of the steel used in the turbine blade. Many researchers investigated the effect of temperature or time on the performance of carburizing process, but in this work both time and temperature with range not exceeding 1000C studied to find the optimum condition to get the higher surface properties of steel.

2. Experimental work

2.1. Material selection

The chemical analysis of the low carbon steel 1020 AISI, performed utilizing an ARL Spectrometer, is displayed in Table 1.

2.2. Preparation of specimens

As per ASTM (G99-04) specifications, cylindrical samples for adhesion wear tests were produced with dimensions of 10x20mm [20], disc specimens for hardness tests were prepared with 20 mm diameter and 6 mm height [21], and specimens shown in Figure (1).

2.3. Carburization process.

The various test samples composed of mild steel were pack-carburized before being utilized for assessing wear characteristics and hardness. The mild steel specimens were placed in this procedure on a thick bed of carburized that was completely covered on all sides and stored in a stainless steel container. A steel plate protected the container's top. Once the electrical furnace was, the container was kept at the necessary carburization temps of 850, 900, 950, and 1000 °C for various soaking durations of (0.5, 1, 1.5, and 2) hours before cooling the furnace.

2.4. Testing

2.4.1. Sliding wear testing

The pin-on-disk test was utilized to conduct the wear test following ASTM G99-4 [20]. Equation (1) was utilized to identify the wear rate, and all tests were carried out at room temp for 300 seconds with loads of (5, 10, 15, and 20 N), figure1 showed the schematic of testing equipment. An accurate, sensitive balance weight was utilized to measure the initial weight of the samples (10-4 g). The specimens were taken out after the test, weighed the sample to identify the weight loss caused by wear [20] and then conducted after cleaning the sample with acetone, and dried.

$$Wr = \frac{\Delta W}{2\pi Nrt} \quad (1)$$

$\Delta W = W2 - W1$

Where as:

Wr: the rate of wear in gm/cm.

N: speed (rpm),

$2\pi r$: the distance of sliding (cm).

t: duration.

W1: the weighting before conducting wear test (gm).

W2: the weighting after the conducting wear test (gm).

Table 1. The Chemical analysis of the utilized Steel 1020 AISI

Wt.% of element	C	Si	MN	Cr	Mo	Cu	Co	V	W	Ai	Ni	P	S
Actual value%	0.2	0.009	0.65	0.011	0.004	0.041	0.004	0.0009	0.003	0.001	0.012	0.09	0.05

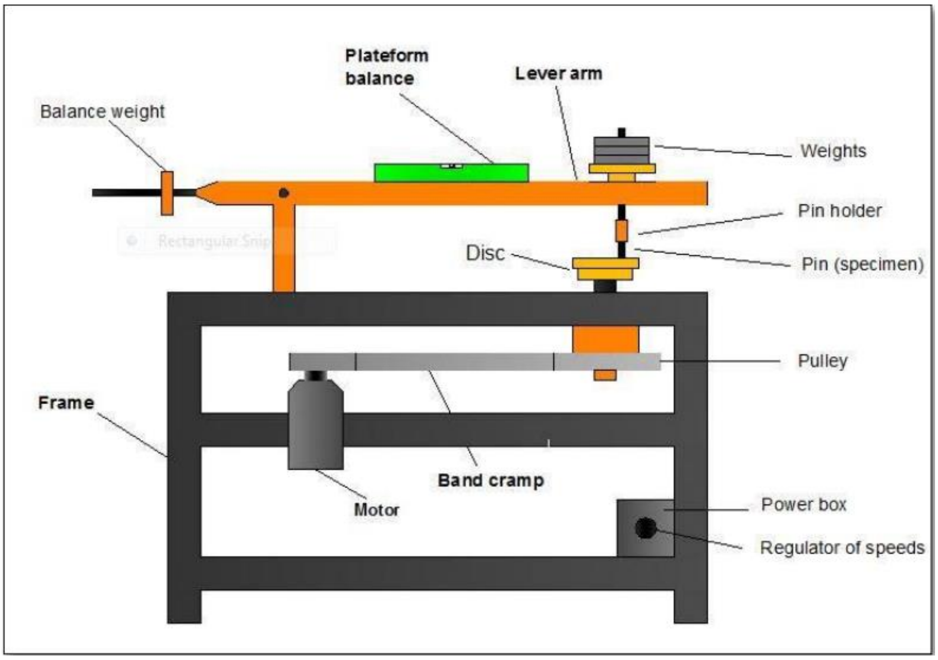

Figure1. Pin-on-Disk Wear Test equipment.

2.4.2. Brinell Hardness

An indentation hardness test called the Brinell Test has two phases. Step one involves applying the prescribed test force while the indenter is brought into contact with the test sample perpendicular to the surface. After holding for the allotted amount of time, the test force withdrew. The indentation diameter is determined in at least two perpendicular directions in step two. According to ASTM E10-17 [21], a mathematical method created specifically for this purpose is utilized to get the Brinell hardness rating from the diameter average measurements.

3. Results and Discussion

3.1. Results and Discussion of Hardness Test

Figure (2) illustrates the results of the Brinell hardness test. As observed, steel becomes harder following the carbonization process, and the value of steel's hardness rises with rising temperatures and lengthening soaking times. The development of unsaturated austenite and the presence of carburizes, such as charcoal, which come into contact with the low carbon steel surface and disperse, are responsible for this increase in hardness. The outcome is the deposition of a very thin coating of exceedingly fine carbon. The steel absorbs this carbon until saturation is reached. Layer thickness rises with temp and time, and as a result, the hardness of specimens will increase [12, 22, 23]. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion.

3.2. Results and Discussion of Wear Resistance Test

For specimens treated to carburizing at temps of 850, 900, 950, and 1000 °C for 30 minutes, Figure (2) depicted the connection between wear rate and applied load. This image illustrates a general association between loads and wear rate, showing that wear rate steadily rises with load for all treatments. After the carburizing process, the wear rate was also noticeably reduced. As the temp of the carburizing process rose, this decrease grew. The production of the carburized layer, which gets thicker and stronger with rising temp and soaking time, causes the growth of resistance against wear for steel specimens. [24,25]. Steel was treated to carburizing at temps of 850, 900, 950, and 1000C° for soaking durations of 60, 90, and 120 minutes, respectively. Figures (3-5) demonstrate the connection between wear rate and load. Given that resistance against wear is a function of hardness, resistance against wear will rise as hardness raises following carburizing heat remediation. The impact of load and wear rate is evident in every situation. Between two sliding surfaces, the plastic deformation increased in the surface tips and peaks. The applied load affects how well the two tip surfaces adhere. If the load is low, the top bit, which was extremely thin during sliding, shows the contact. As a result, a thin oxide film formed, acting as a protective surface coating that restricts contact and prevents direct metallic contact between the two sliding surfaces. As a result, less force is needed to break the connection between the two surfaces than there is between the metal atoms themselves. The wear rate will drop as a result [25], low carburizing temperature with less holding time having higher wear resistance and lower wear rate than with more time. This sometimes happens if the amount of carbon in the carburizer and energizer has been exhausted, in such case prolonging the holding time at higher temperature may not have much significant effect on the steel [18].

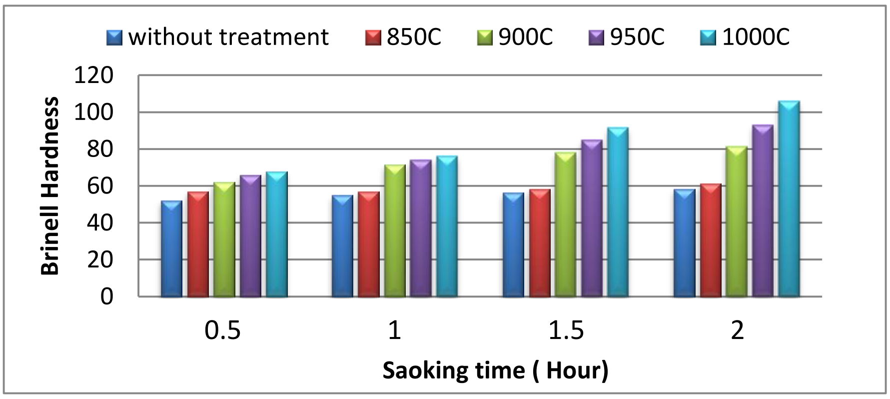

Figure 2. Brinell hardness for specimens subjected to Carburizing with different temperatures for different soaking times.

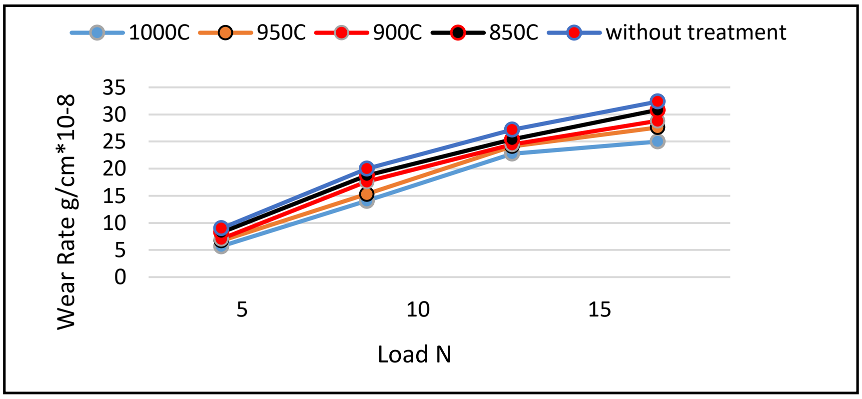

Figure 3. Rate of wear for specimens subjected to Carburizing with different temp with a soaking time of 30 min

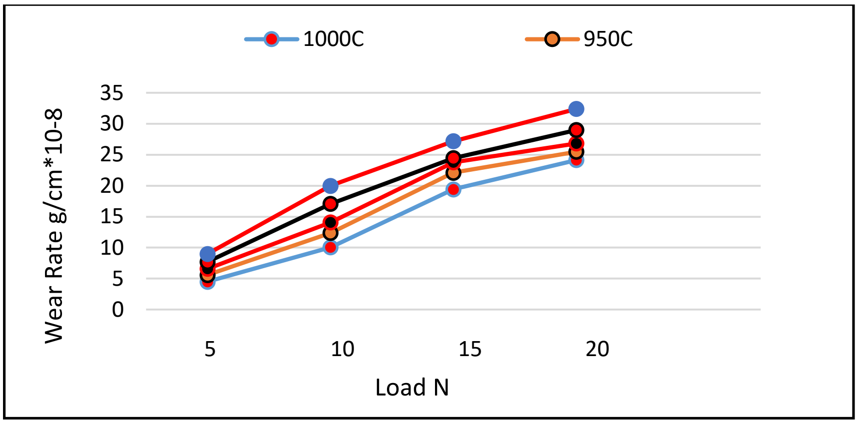

Figure 4. Rate of wear for specimens subjected to Carburizing with different temp with a soaking time of 60 min

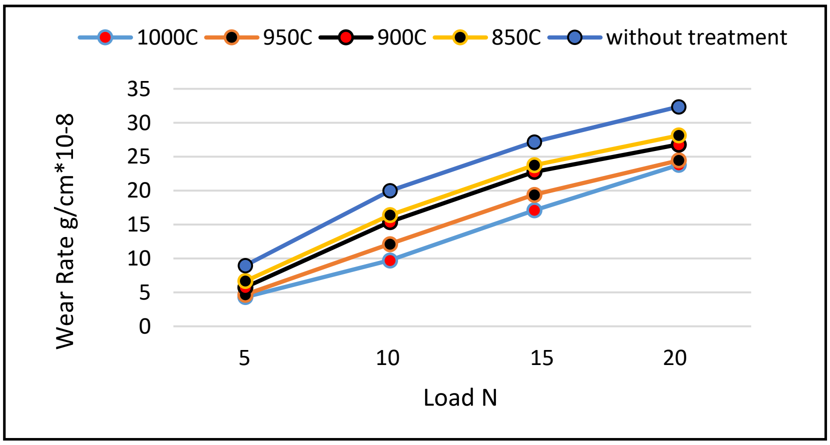

Figure 5. Rate of wear for specimens subjected to Carburizing with different temp with a soaking time of 90 min

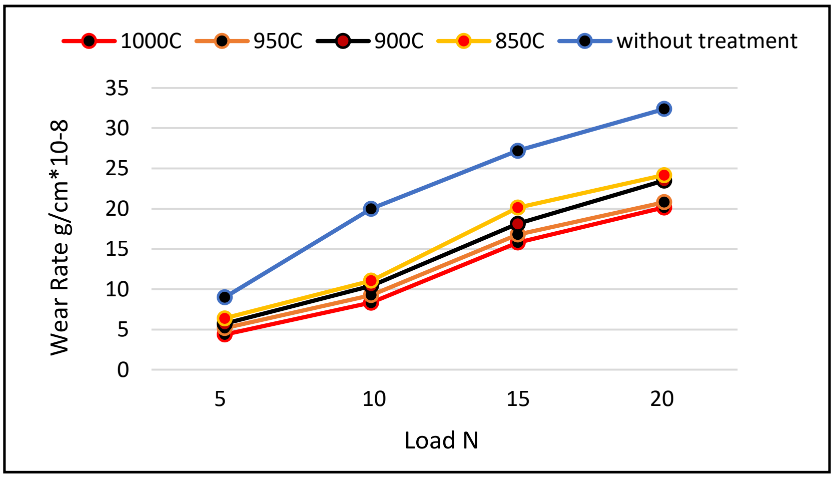

Figure 6. Rate of wear for specimens subjected to Carburizing with different temp with a soaking time of 120 min

3.3. EDX Results

It was decided to analyze the microstructure of steel specimens. After the carburizing procedure, the samples were obtained from treated samples. The samples were air-dried at room temperature before SEM-EDX analysis and examination. Figures (7-11) display the micrograph of an EDX examination of steel that has been carburized at temperatures of 850, 900, 950, and 1000 C. Due to the production of the martensitic phase during heat remediation that makes steel tougher and stronger than parent steel, EDX discovered that steel samples with one phase (pearlite), but after remediation, revealed multi-phases, making them more suitable for turbine impeller. More peaks of carbon with extraordinary intensity have been identified as during carburizing, carbon can diffuse into the specimens from the surface, resulting in a carbon gradient distribution in the near-surface case. This demonstrates that active carbon layers were formed during the carbonization process, which greatly improved the mechanical characteristics of steel by boosting resistance against wear and surface hardness [10,26,27]. According to theoretical calculations based on the iron-carbon phase diagram, the absolute dissolution of carbides could occur only at temperatures higher than 880 °C. This indicates that more austenite was retained at a higher austenitizing temperature. Because of the increased number of carbides dissolved into austenite, the carbon content in the austenite is higher [28]. All of the above supports and explains the reasons for increase in wear resistance and hardness with increasing carburizing temperature.

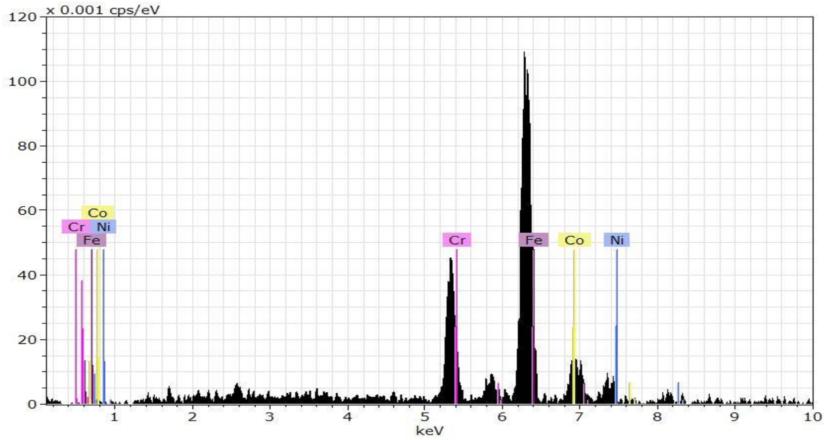

Figure 7. EDX analysis for specimen before carburization

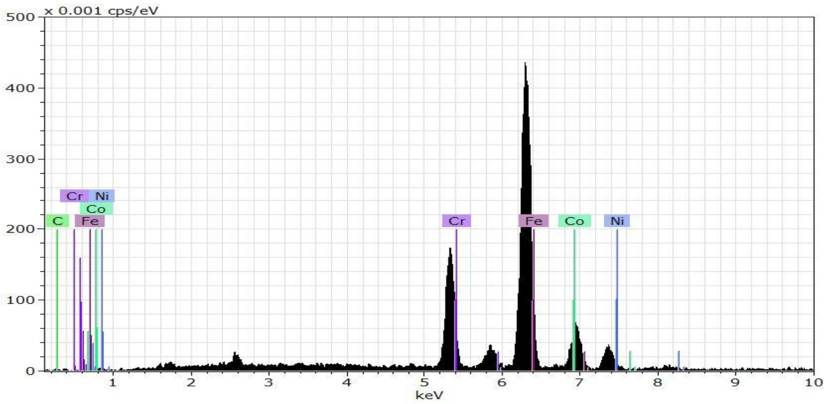

Figure 8. EDX analysis for specimen subjected to Carburizing at 850C°

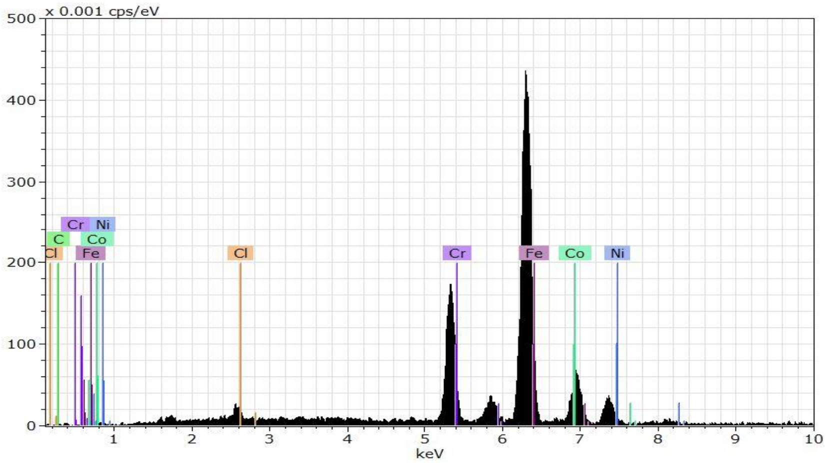

Figure 9. EDX analysis for specimen subjected to Carburizing at 900C°

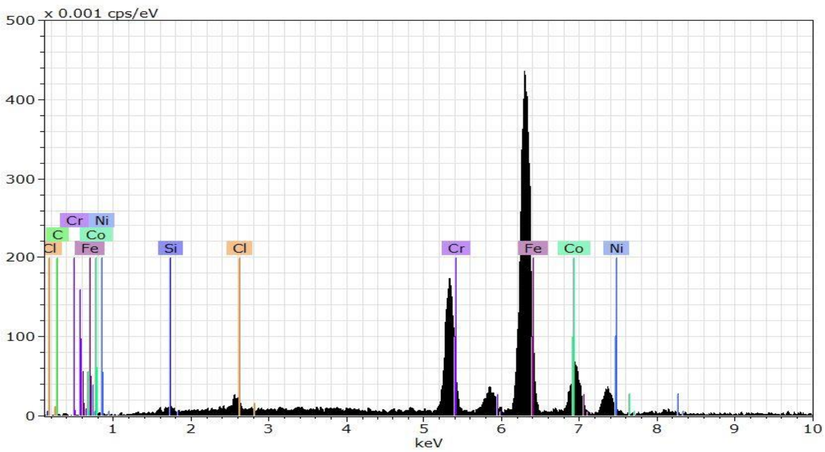

Figure 10. EDX analysis for specimen subjected to Carburizing at 950C°

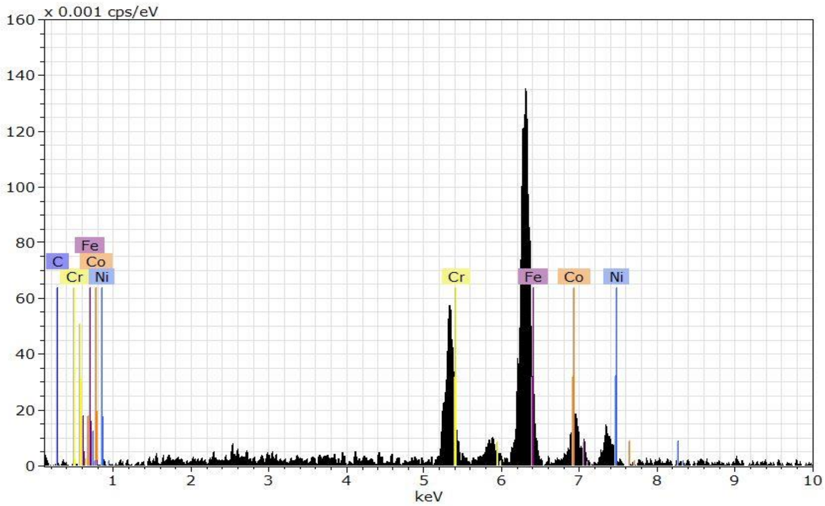

Figure 11. EDX analysis for specimen subjected to Carburizing at 1000C°

4. Conclusion

The carburizing process can be characterized by the following key points: It is applied to low-carbon work pieces such as turbine blade; work pieces are in contact with a high-carbon gas, liquid or solid; it produces a hard work piece surface; work piece cores largely retain their toughness and ductility. The following conclusions could be drawn depending on the finding presented in this study.

1. Carburizing treatment showed a remarkable improvement in resistance against wear and surface hardness for low-carbon steel.
2. Increasing temp of the carburization process and increasing time lead to more development in mechanical and surface properties of steel
3. A more activated carbon layer with acceptable thickness can be obtained by raising the temperature and increasing the heat remediation time.
4. To obtain an impeller turbine with higher resistance to erosion, it is recommended to utilize steel after exposure to the carburization process at 1000C with a soaking time of about 2hrs.

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