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Research Article

# IMPROVING EROSION PROPERTIES OF STEAM TURBINE BLADES VIA SURFACE MODIFICATIONS

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**ABSTRACT**

Steam Turbines can generate electricity by using various sources of heat. This is the main reason it is one of the most common type of turbine used in power plants. Steam turbines are composed of various number of stages and each stage is composed of one set of blades. Towards the last stages, water in the steam increases and due to the fact that water velocity is higher than steam velocity, water droplets scatter with the momentum striking at the surface of the turbine blades and causes erosion. Steam turbine blade service life is expected to be not less than 100.000 hours which is approximately 12 years. Blade materials should be considered carefully and necessary surface modifications should be made accordingly.

The material is usually selected as martensitic stainless steel due to the service conditions. Steam turbine blades, especially those working in the low pressure region, are subjected to wet steam and their tips are eroded heavily. In this study, a typical low pressure turbine blade material, 1.4021, steel surface has been modified with laser hardening, tungsten carbide coating, and chromium carbide coating. The samples were tested using erosion testing equipment and the results were compared.

**Keywords:** Steam turbine blades, martensitic steels, HVOF, laser hardening, erosion.

## 1. INTRODUCTION

Steam turbine blades are studied extensively in order to increase the service life and decrease manufacturing costs. Erosion is caused by the wet steam swept on the surface of the blades. Since wet steam is only formed on the low pressure part and later stages of the turbine, these materials limit the service life of the turbine blades. Many researchers studied cavitation erosion problem on steam turbine blades by applying different coatings or by surface modifications. [1] [2] [3]. It has been reported that resilience to erosion is correlated with hardness of the surface and ultimate tensile strength of the substrate material [4] [5]. Laser hardening of the surface of the steam turbine blade has been studied with favorable results [3], [6] [7] WC based coatings applied with HVOF has been studied for steam turbine blades and had favorable results [2]. $Cr_3C$-NiCr coatings are used extensively in turbine industry as a solution for erosion of boiler walls [8] [9] [10].

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In this study, samples manuf actured with laser hardening, HVOF tungsten carbide coating, HVOF $Cr_3C$-NiCr coating and cryogenic hardening are tested with erosion testing equipment built with respect to ASTM G73.

## 2. MATERIALS AND METHODS

Substrate material used in this study is AISI 420(1.4021), a martensitic stainless steel. The samples were machined as round bars in order to study the effect of curved surface. All the substrate material was wrought and has been conventionally heat treated.

**Table 1.** Chemical Composition of the Substrate Material (Spectro)

| C | Si | Mo | V | Mn | Ni | Cr | P | Fe |
|---|---|---|---|---|---|---|---|---|
| 0,241 | 0,216 | 0,099 | 0,02 | 0,674 | 0,574 | 13,270 | 0,006 | 84,900 |

### 2.1. Laser Hardening

Laser hardening parameters given in Table.2 was experimented on the samples, hardness results of each sample was compared Fig.1. The results revealed that parameters with number 2, has better effect of the hardness of the material. Consequently the samples that were treated with number 2 were selected for erosion tests.

**Table 2.** Laser Hardening Parameters

| No: | Pulse Duration | Velocity | Temperature | Power |
|---|---|---|---|---|
| 1 | 0,2sec | 6mm/cm | 1100-1300°C | 1800-3000W |
| 2 | 0,2 sec | 4mm/cm | 1100-1200°C | 1800-3000W |

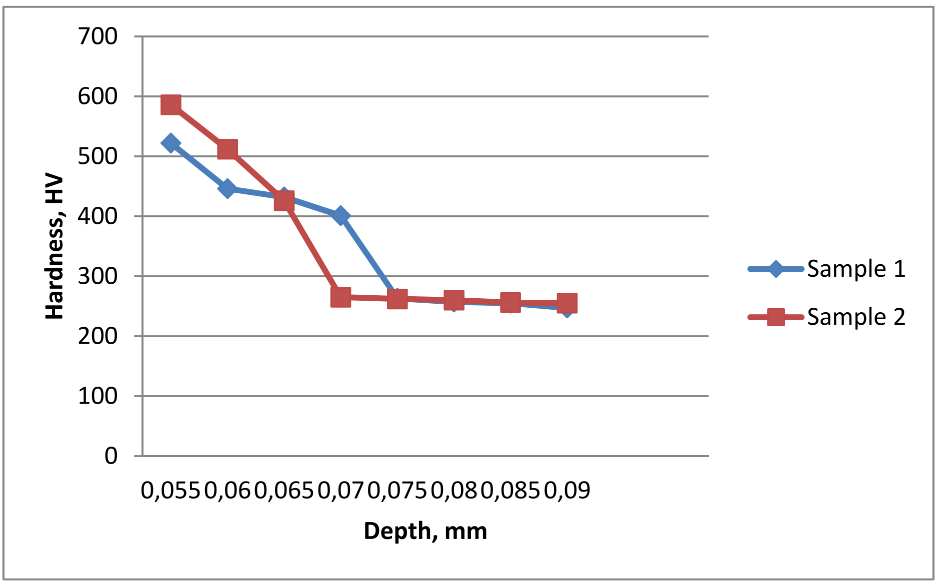



**Figure 1.** Vickers Hardness Comparison Chart

### 2.2. WC-Co Coating

TAFA JP5000 is a kerosene fuelled, high pressure HVOF gun. Powder composition is 88%WC-12%Co. The coating thickness was 90-110µ. The coating parameters are given in Table.3.

**Table 3.** Spraying parameters for WC coatings

| | |
|---|---|
| Kerosane(fuel) | 97 ± 10 psi |
| Oxygen | 138 ± 10 psi |
| Argon | 50 psi |
| Coating Chamber | 97 ± 5 psi |
| Spraying Distance | 350 mm |
| Nozzle | 4 inch |
| Temprature of the sample during | 70-100□C |
| Surface Roughness after coating | Ra 5-7 µ |
| Hardness, mean value | 996,82HV |

### 2.3. Cr3C-NiCr Coatings

TAFA JP5000 is a kerosene fuelled, high pressure HVOF gun. Powder composition is 80% Cr3C-20% NiCr. The coating thickness was 90-110µ. Coating parameters are given in Tablo.4.

**Table 4.** Spraying parameters for $Cr_3C$-NiCr coatings

| | |
|---|---|
| Fuel(Kerosane) | 112 ± 10 psi |
| Oxygen | 170 ± 10 psi |
| Argon | 50 psi |
| Coating Chamber | 100 ± 5 psi |
| Spraying Distance | 340 mm |
| Nozzle | 4 inch |
| Temprature of the sample during | 70-100□C |
| Surface Roughness After Coating | Ra 5-7 µ |
| Hardness, mean value | 400,98 HV |

### 2.4. Erosion testing equipment

Erosion testing equipment was manufactured according to Standard Test Method for Liquid Impingement Erosion Using Rotating Apparatus, ASTM G73. Samples were mounted on a rotating disc. The rotating disc was connected to a motor with a speed of 3000rpm. A high pressure water stream was introduced through one point on the rotating disc, so that each sample would pass through stream of high pressured water. Water pressure was regulated at 100mbar in order to simulate turbine conditions. A precision balance with an accuracy of 0.001 was used to weight the samples before and after. The system was stopped periodically to weight the samples. Before weighing, the samples were dried in a drying oven for at least 16 hours.

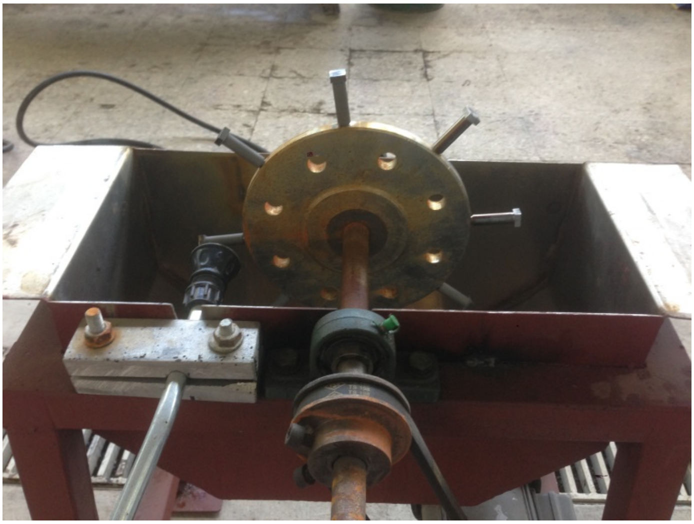


**Figure 2.** Erosion equipment

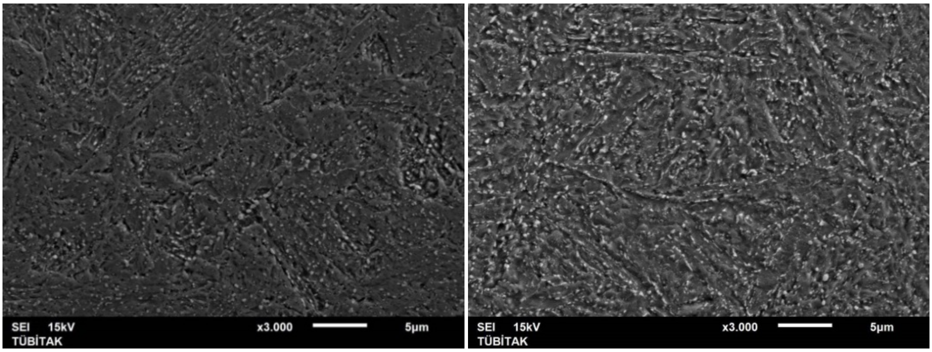
### 2.5. Erosion Tests

Erosions tests were conducted with the erosion equipment described above. The experiment was stopped periodically to examine the condition of the coating. After 180h , 258h, 302h, 350h, 387h and 425h. The test was stopped periodically and macro images were taken to determine the affected area. Affected areas were analyzed with ImageJ software and the results are presented in Figure3,4 and 5.

## 3. RESULTS AND DISCUSSION

### 3.1. Results of Laser Hardening

Laser hardening is used to harden martensitic steels for various reasons. Laser hardening parameters were set to make sure that the surface is hardened enough and is defect free. The hardening mechanism depends on the carbide composition and distribution. With high laser energy, chromium carbide ($(Fe,Cr)_3C$) in globular form is dissolved in to the matrix [6]. Figure 3 reveals SEM image of the both samples. Sample1 shows globular carbides however Sample2 shows less globular carbides which led to higher hardness values.




(a) (b)

**Figure 3.** SEM image of laser hardened samples, Sample1 (a) and Sample(2)

### 3.2. Erosion Test Results

Erosion test was performed with laser hardened sample, Tungsten Carbide coated sample and Chromium Carbide coated sample. Samples were controlled visually.

Figure4 reveals erosion test results after exposure to erosion conditions. Until 180 hours the surface was not affected visually. The affected area increased with increasing exposure however even after 425hours the surface was only slightly eroded. The area affected was the smallest in all other samples.

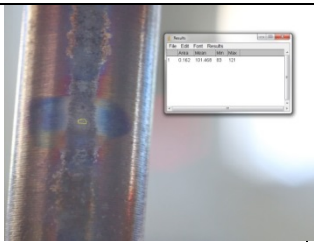
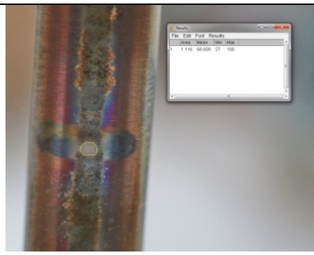
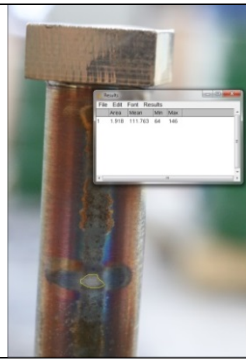
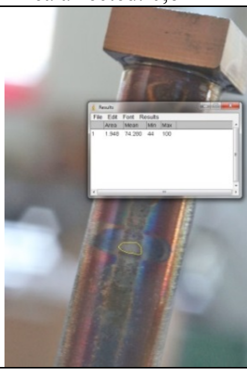
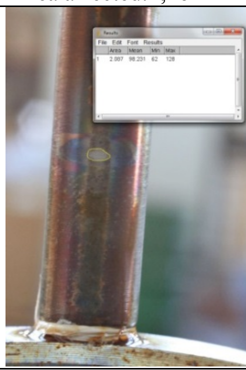
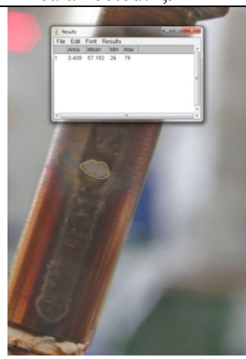
| | | |
|---|---|---|
|  |  |  |
| 180hrs | 258hrs | 302hrs |
| Area affected: 0,62 $mm^2$ | Area affected:1,16 $mm^2$ | Area affected:1,91 $mm^2$ |
|  |  |  |
| 350hrs | 387hrs | 425hrs |
| Area affected:1,95 $mm^2$ | Area affected:2,09 $mm^2$ | Area affected:3,41 $mm^2$ |

**Figure 4.** Laser Hardened Sample affected area measurement after erosion tests of durations 180h, 258h, 302 h, 350h, 387h, 425h

Tungsten carbide is used in erosion environments due to its superb hardness values [1]. The surface was affected immediately after the exposure. Although erosion resilience is attributed to hardness, [4] and the surface hardness values (Table.3) are near 900HV, three of the WC coated samples failed the same way. The area affected is the largest in all samples.

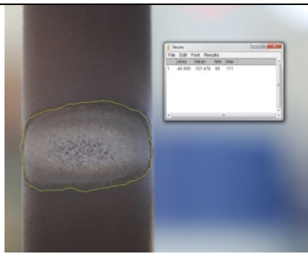
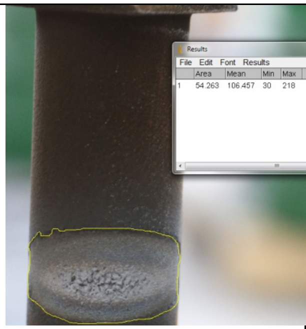
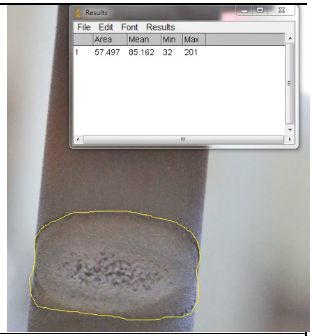
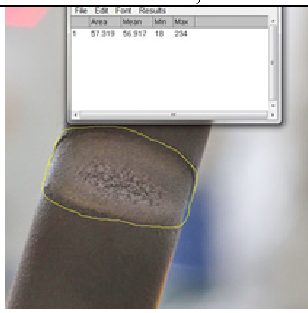
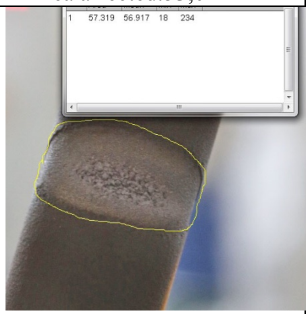
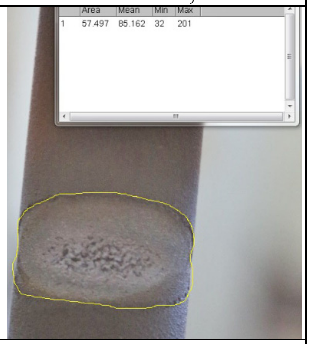
<table>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr><td>180h</td><td>258h</td><td>302h</td></tr>
<tr><td>Area affected: 45,90 mm$^2$</td><td>Area affected:53,01 mm$^2$</td><td>Area affected:54,26 mm$^2$</td></tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr><td>350h</td><td>387h</td><td>425h</td></tr>
<tr><td>Area affected: 54,615mm$^2$</td><td>Area affected:57,32 mm$^2$</td><td>Area affected:57,49 mm$^2$</td></tr>
</table>

**Figure 5.** WC coating Samples affected area measurements after erosion tests of durations 180h, 258h, 302 h, 350h, 387h, 425h

The $Cr_3C$-NiCr coatings have been used against hot erosion and corrosion in turbines. [11] The hardness values were moderate around 400HV (Table.4). Although WC coating hardness values are significantly higher than $Cr_3C$-NiCr, the affected area after exposure to erosion is measured as lower.

| | | |
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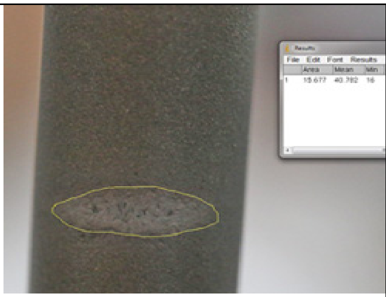
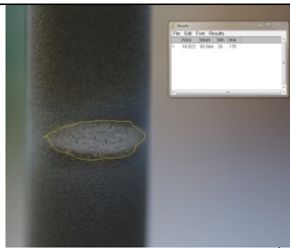
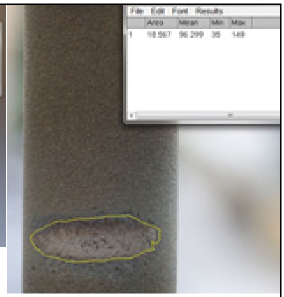
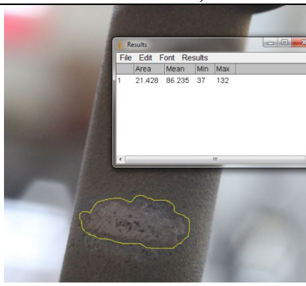
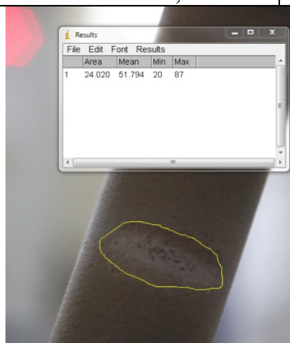
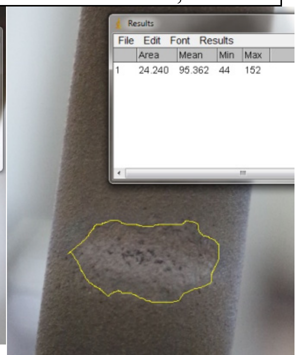
|  |  |  |
| 180h | 258h | 302h |
| Area affected: 15,67 mm$^2$ | Area affected:18,02 mm$^2$ | Area affected:18,57 mm$^2$ |
|  |  |  |
| 350h | 387h | 425h |
| Area affected:21,43 mm$^2$ | Area affected:24,02 mm$^2$ | Area affected:24,24 mm$^2$ |

**Figure 6.** Cr3C-NiCr Coating samples affected area measurements after erosion tests of durations 180h, 258h, 302 h, 350h, 387h, 425h

After test the samples were cut through the cavity and analyzed with metallographic methods. The cross section of the affected area was measured in order to determine the erosion depth. The images were analyzed with Image J software to determine the erosion depth area. [12]

| | |
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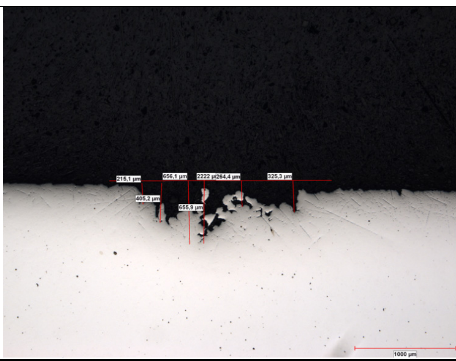
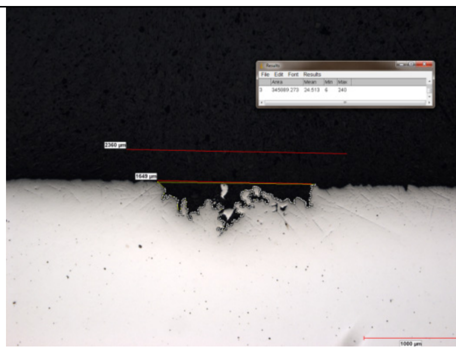
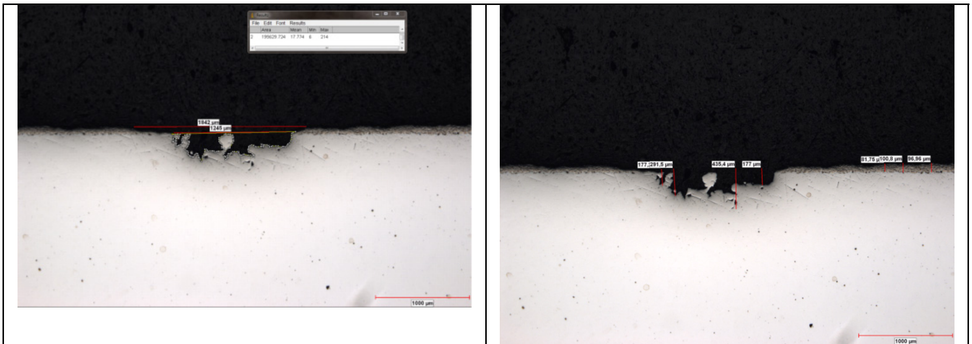
|  |  |
| Area: 324396.582 µm$^2$ | Area:345889,273 µm$^2$ |

**Figure 7.** WC coatings , 2.5X optic microscope

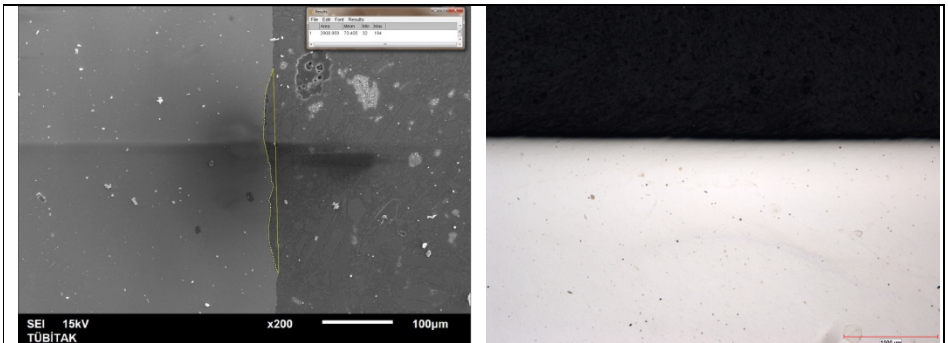
WC coatings showed the largest affected area after erosion tests. The depth of the cavity is about 600µm and the width of the cavity is around 2300µm. Although all of the samples are subjected to the same water droplets, the cavity left after exposure to erosion is much larger than all the other samples. WC coating has been stripped from the surface of the material immediately after exposure.



| | |
|---|---|
| Area:195629.724 µm$^2$ | Area: 146833,863 µm$^2$ |

**Figure 8.** $Cr_3C$-NiCr coating , 2.5X optic microscope

$Cr_3C$-NiCr coated samples showed better performance than WC coated samples. The depth of the cavity is about 400µm and the width of the cavity is about 1200µm. $Cr_3C$-NiCr coating has been stripped from the surface only on the contact region which suggests the $Cr_3C$-NiCr coating has better adhesion than WC coatings.




| | |
|---|---|
| Area: 2908,959 µm$^2$ | Not visible with optical microscope |

**Figure 9.** Laser Hardened samples, SEM and 2.5X optic microscope

Laser hardened samples showed excellent performance during erosion tests. The area affected could only be seen by scanning electron microscope.

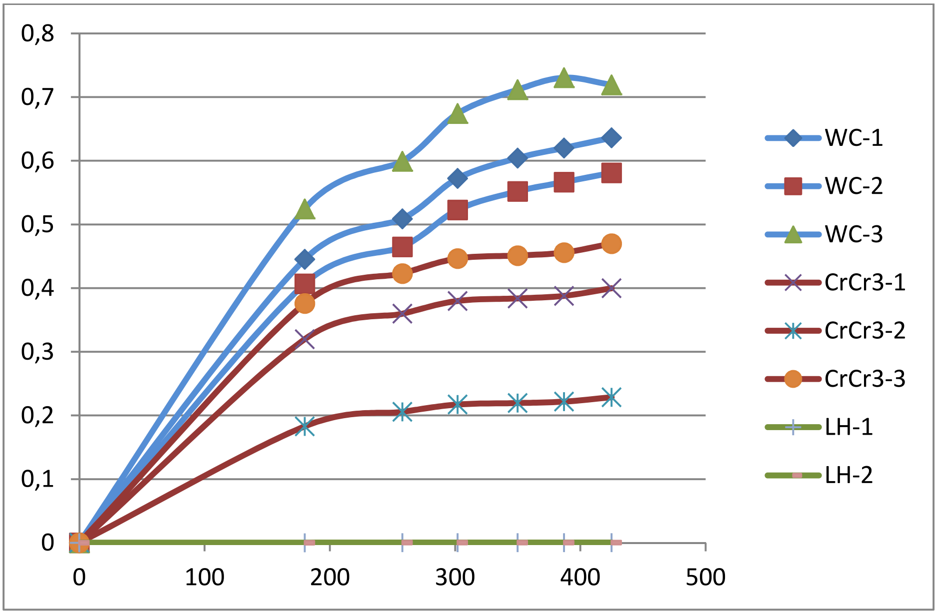



**Figure 10.** Cumulative Erosion-Time Curves,

## 4. CONCLUSIONS

WC coatings showed a large weight loss, also the area affected on the test surface was larger than all other samples.

$Cr_3C$-NiCr coated samples showed better performance than WC coated samples, however their performance was not as good as laser hardened samples.

Although Cr3C-NiCr and WC coated samples were both coated with HVOF method, the failure type of both coatings were different from each other. Both failed in brittle mode, however WC coated samples were stripped from the surface of the base material. $Cr_3C$-NiCr coated samples hardness values were lower than WC coatings, and yet $Cr_3C$-NiCr coated samples showed better performance which suggests $Cr_3C$-NiCr coated samples have better adhesion than WC coated samples.

Laser hardened samples showed excellent performance. Although, visual inspection showed some deformation on the surface of the sample, the metallographic inspection and weight difference showed minimal degradation. Laser hardening parameters, turbine blade geometry and design should be explored in future studies.

**Acknowledgements**

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