Analysis of surface treatment of ASTM A516 Grade 70 using Salt spray method

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Abstract. Conversion coating is an effective way to safeguard against corrosion. It is performed on a number of materials inhibiting the surface layer to corrosive attack. In this work surface engineering is carried out on test material ASTM A 516 Grade 70 which is widely used for constructional purposes. During the passivation process samples were given a hot alkaline oxide bath in sodium hydroxide and sodium nitrate. The corrosion resistance was then analyzed using advanced testing procedures. Salt spray test was used as a yardstick in making a comparative analysis of different samples including unpassivated samples, passivated samples and passivated samples with prior surface treatment. Results have shown that mechanical surface treatment improves material life by 3% whereas passivation with prior surface treatment can increase life by 18%.

Keywords: Surface Engineering, Passivation, ASTM A516 Grade 70, Salt spray method,

1. Introduction

Metals, which makes up most of the periodic table (91 out of 118), are elements which possess good thermal and electrical conductivities[1]. They are opaque and shiny as well as ductile, malleable and fusible. Material especially metals undergo chemical reactions with the surrounding and are transformed into a more stable shapes. Corrosion is a combination of oxidation-reduction reaction collectively known as redox reactions[2]. The base metal acting as anode gets oxidized primarily by the oxygen present in the air. As a result metal ion is produced and free electrons are liberated which reduces oxygen forming hydroxide ions in presence of water. Final product is Iron Oxide (Fe₂O₃) commonly known as rust. This is a highly unstable and readily disintegrating product which causes pitting and adversely affects mechanical strength. A numbers of factors govern the initiation, propagation and transformation of corrosion [3]. A few act as basic ingredients required for the process of corrosion while others acts as catalysts. The reactivity of metal known as oxidation state defines the speed of redox reactions[4]. Highest oxidation state is that of iridium tetraoxide cation, i.e +9 and lowest is -5 for boron, gallium, indium and thalium. Corrosion causes huge losses in different industries by wasting resources and degrading finished and unfinished materials. According to one
estimate corrosion damage amounts to about 4% of Gross Domestic Product (GDP) of a country[5]. Researchers have used different methods to counter the process of corrosion. A detailed study was carried out by M. Fenker et al[6] on anti corrosive properties of hard coatings on steel surface. Film growth, microstructure and defects were analyzed. It was concluded that a 10 µm thick single layered nitrite coating is effective against corrosion. Another study [7] showed that surface treatment plays a vital role in the subsequent anti corrosion effectiveness of coatings. Surface treatment in some cases alters the mechanical structure of surface layer whereas thermal and electrical conductivities can also be altered which significantly affects the coating properties. Passivation process or conversation coating is a highly efficient process in which the outer surface of a corroderible material is made resistant to corrosion. H. Zhu et al [8] carried out a process called hot alkaline nitrate (black oxidizing) bath. This process deposits magnetite Fe₃O₄ on the outer surface which protects the base material from corrosion. E. Onofre-Bustamente et al [9] highlighted that conversion coating in addition to the corrosion protection also increases the adhesiveness of coating to substrate. E. Banczek[10] showed that corrosion resistance of carbon steel can be substantially increased by adding benzotrizole to zinc Phosphating bath. Research carried out by Y.-W. Choi et al [11] compared the effects of anodizing, annealing and combination of both in terms of corrosion protection. Corrosion protection by single annealing was in amorphous phase and comparatively weak. A positive shift in tafel plot was observed by corrosion potential when anodizing and annealing were used in combination. S. B. Abusulik et al [12] carried out a research to examine the effects of intermediate surface treatments. These included micro blasting with two types of blasting media, Ar ion Plasma etching followed by Ti ion bombardment. It was shown that the use of intermediate surface treatment greatly enhances the performance of cathode arc coatings. Research motivation for this study is to explore the benefits of passivation in combination with surface treatment. The aim is to find an effective yet economical way to increase corrosion protection without compromising on strength.

2. Experimental setup

ASTM A516 grade 70 was selected for experimentation and analysis. It is largely used for constructional purposes where its high strength and durability is utilized. Its chemical composition is given in Table 1. Test material is also the preferred choice industrially making pressure vessels and boilers because of its toughness. Its mechanical properties are given in Table 2.

| C = 0.10 – 0.28% | Mn = 0.85 – 1.2% | P = 0.010 – 0.035% | S = 0.010 – 0.035% |
|-----------------|-----------------|------------------|------------------|
| Si = 0.15-0.40% |                 |                  |                  |

Table 2. Mechanical properties of ASTM A516 grade 70

| Yield Strength | 424 N/mm² |
|----------------|----------|
| Tensile Strength | 511 N/mm² |
| Elongation | 24 % |

3. Design of experiment – Sample preparation

Different types of samples were prepared as tabulated in Table 3 with dimensions of 8 x 5 inches. Type 1 was untreated samples cut from the original material. Type 2 samples were made by surface treating the original samples. An emery paper grinder was used for surface treatment. RPM was set at 3000 revs and grit size of 300 µm was used. Type 3 samples were made by treating original material in hot alkaline oxide solution for 45 minutes at 130°C. The solution had the aqueous mixture of sodium Nitrate (NaNO3) and sodium Hydroxide (NaOH) in 1:3ratio. An outer layer of Fe₃O₄ (magnetite) is
formed which prevents base material from corrosion. Type 4 was prepared by first surface treating the samples by emery paper grinding and then giving them the hot alkaline passivation bath. These sample types are shown in Fig. 1. Three samples of each type were made and tested for taking average values.

| Sample | Surface Treatment | Conversion Coating |
|--------|-------------------|--------------------|
| Type 1 | x                 | x                  |
| Type 2 | ✓                 | x                  |
| Type 3 | x                 | ✓                  |
| Type 4 | ✓                 | ✓                  |

4. Experimentation
Samples were then kept in salt spray chamber as shown in Fig. 2. In this test the samples were exposed to an atomized 5% NaCl solution for 48 hours in a controlled environment at 40°C temperature and 60% humidity. Such atmosphere is strongly corrosive as it attacks the surface and accelerates the phenomenon of corrosion. After Salt spray test, bending test of samples was carried out on Tinius Olsen H150KU with bending testing kit installed as shown in Fig. 3. The samples were bent under force up to and beyond their elastic limit until they bend plastically.

5. Results and Analysis
The initial and final weights were calculated and compared. The weight loss and strength results are as shown in Table 4.
Table 4. Salt spray and bending test results

| Sample Type | Salt Spray Results | Bending Test Results |
|-------------|--------------------|---------------------|
|             | Initial Weight (g) | Final Weight (g)    | MPa     |
| 1           | 232.82             | 209.63              | 729     |
| 2           | 237.97             | 230.86              | 782     |
| 3           | 233.74             | 222.48              | 761     |
| 4           | 234.50             | 233.44              | 791     |

5.1 Weight loss analysis

Weight loss is a direct indication of the extent of corrosion that has occurred. The corroded portion of the sample was washed away and the weight loss was analyzed as shown in Fig. 4. It was evident from the results that Type 4 sample was the least corroded because of surface treatment and passivation. Type 2 gave the second best result. Its good performance was because of the surface passivation which resisted corrosion. Type 3 was only surface treated and offered even lesser resistance. Type 1 had no protection against corrosion and lost significant amount of weight due to redox reactions.

5.2 Strength analysis

The purpose of this test was to analyze any strength reduction that has occurred to the original material because of the surface treatment or surface passivation process. The results displayed in Fig. 5 shows that strength has not been compromised because of the surface treatment procedures. Interestingly it was observed that strength was improved because of the surface treatment and passivation. The reason here is the change in surface morphology and it can well be concluded that the treatment for improving corrosion resistance has not compromised on strength.

6. Conclusion

During the course of experimentation, testing and analysis following conclusions were reached:

1. ASTM A516 Grade 70 is a corrodeable alloy of iron and needs to be protected as Type 1 sample corroded 9% of its body weight.
2. Surface treatment of test material by emery paper grinding has proved to be a simple yet effective way of resisting corrosion. It improved life by 3%.
3. Conversion coating on test material has produced good protection against corrosive attack. It passivates the outermost layer by oxidizing.

4. Surface treatment prior to conversion coating adds manifolds to the potential barrier of resistance to corrosion by increasing material life around 18%.

5. Strength is not compromised by surface treatment using emery paper grinding or conversion coating using hot alkaline oxide bath as evident by bending tests.

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