3rd International Conference on Recent Innovations in Science Engineering and Management
Sri Venkateswara College of Engineering and Technology,Srikakulam,Andhra Pradesh (ICRISEM-16)
27 February 2016, www.conferenceworld.in ISBN: 978-81-932074-1-3

EFFECT OF CHROMIUM ON MECHANICAL PROPERTIES OF A487 STAINLESS STEEL ALLOY

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ABSTRACT

The most important characteristics common to all chromium-containing alloys, among them stainless steels, is that they contain sufficient chromium to make them corrosion resistant, oxidation resistant and heat resistant. In the current study four different steels samples with varying weight percentages of Cr have been developed to observe the effects of alloying elements. The effects have been characterized according to the presence of alloying elements either alone or in conjunction with each other in the low carbon steel samples. The steel samples have been characterized using mechanical testing method. Tensile strength, hardness test, chemical analysis and microstructure data have been collected to compare the effects of alloying elements. Alloy developed in current investigation poses better strength and hardness.

Keywords:* *Casting, Chromium, Mechanical Characterization, Steel Alloy

I. INTRODUCTION

All the steel alloys contain chromium (Cr), manganese (Mn), silicon (Si), carbon (C), nitrogen (Ni), sulphur (S), and phosphorus(P), and may contain: nickel (Ni), molybdenum(Mo), titanium (Ti), niobium (Nb), zirconium (Zr), copper (Cu), tungsten (W), vanadium (V),selenium (Se), and some other minor elements. For resisting corrosion and oxidation at elevated temperatures, alloy steels are essential. The Alloy Steels Research Committee adopted the following definition: 'Carbon steels are regarded as steels containing not more than 0.5% manganese and 0.5% silicon, all other steels being regarded as alloy [1]. The principal alloying elements added to steel in widely varying amounts either singly or in complex mixtures are nickel, chromium, manganese, molybdenum, vanadium, niobium, silicon and cobalt.

Chromium enhances corrosion resistance indirectly. The corrosion rate of Fe-Cr alloys decreases drastically within a narrow concentration interval (9-13 wt. % Cr).[2] Chromium oxide gives good corrosion protection at usual operating temperatures but since Cr forms volatile compounds at high temperature the corrosion protection at elevated temperatures requires, for instance, the more stable Al oxide scales on the alloy surface. Cr2O3 scale is protective up to 1000-1100 °C whereas Al2O3 scales up to 1400 °C. Unfortunately, for most of the Fe alloy applications the straightforward procedure to improve high temperature corrosion resistance by increasing the Al content in bulk, is not an acceptable solution. This is because the high Al content makes Fe-Al alloys brittle which poses a natural upper bound for the Al content in these alloys regarding to most of the applications [3]. Fortunately, the additional alloying of Fe-Al with Cr boosts the formation of the Al oxide scale on the surface up to such a level that the Al content in bulk can be kept within the acceptable limits regarding to the required mechanical properties of the alloy. This phenomenon, called the third element effect, is still considered a phenomenon without generally accepted explanation [4, 5]. The addition of Cr significantly slows down the rate of recrystallisation in low carbon steel [6]. In most of the cases an increase in the alloying with identical heat treatment improves the strength and reduces ductility and toughness [7, 8].

Table 1 Standard Chemical composition of A487 Alloy

Element	C	Si	Mn	Cr	Ni	Mo	Fe
Percentage	0.15	<=1.0	<=1.0	11.5-14.00	3.5-4.5	0.4-1.0	77.6 - 84.6

Standard chemical composition of A487 alloy has been mentioned in Table 1[9]. Ultimate Tensile strength of A487 alloy with standard configuration have found to be 690 N/mm^2 . In the current study four different steels samples with varying weight percentages of Cr have been used to observe the effects of alloying elements. The effects were characterized according to the presence of alloying elements either alone or in conjunction with each other in the low carbon steel samples. The steel samples were characterized using mechanical testing method. Tensile strength, hardness test chemical analysis and corrosion data have been collected to compare the effects of alloying elements.

1.1 The Role of Chromium in Stainless Steels

The properties that distinguish stainless steels i.e. Fe-Cr-(Mo) alloys and Fe-Cr-Ni-(Mo) alloys from other corrosion-resistant materials depend essentially on chromium. The high degree of reactivity of chromium is the basis for the effectiveness of chromium as an alloying element in stainless steels. The resistance of these metallic alloys to the chemical effects of corrosive agents is determined by their ability to protect themselves through the formation of an adherent, insoluble film of reaction products that shields the metal substrate from uniform and localized attack. The protective film called passive layer or passive film. It is a very fine layer on the surface, of the order of 1.0 to 2.0 nm, which reduces the corrosion rate to negligible levels and has a structure similar to chromite. As with manganese, chromium has a tendency to increase hardness penetration. This element has many interesting effects on steel. When 5 percent chromium or more is used in conjunction with manganese, the critical quenching speed is reduced to the point that the steel becomes air hardening. Chromium can also increase the toughness of steel, as well as the wear resistance. Probably one of the most well known effects of chromium on steel is the tendency to resist staining and corrosion. Steels with 14 percent or more chromium are referred to as stainless steels. A more accurate term would be stain resistant. Stainless tool steels will in fact darken and rust, just not as readily as the non stainless varieties. Steels with chromium also have higher critical temperatures in heat treatment.

II. EXPERIMENTAL WORK

The objective of this work has been to study effect of varying chromium percentage on properties of Stainless steel grade A487. Test samples for the study have been prepared by casting at Devyani alloys. For this purpose temporary sand mould has been prepared and initially cylindrical test samples of approximately 30mm diameter have been prepared. These samples further machined and prepared for tension test. Figure 1 shows the photograph of test samples.

III. TESTING OF SAMPLES

Different mechanical tests have been conducted on test samples in order to investigate the effect of chromium percentage on mechanical properties of alloy steel. These tests include chemical analysis, hardness test and tension test.

Fig. 1 Alloy samples after testing

3.1 Hardness Test

Hardness test has been conducted on prepared alloy samples in order to investigate the effect of chromium percentage on hardness of steel. Brinell Hardness Testers from Shimadzu, Japan and LECO Corporation, USA were used for test. Tests have been conducted as per ISO 6506-1:2005 standards. Test has been conducted at 24 °C temperature, with 2.5mm diameter WC ball and load of 31.25kg applied for 10 to 15 seconds

3.2 Tension Test

Tension Test has been conducted on specimen for finding out Ultimate tensile strength of Alloy steel. Test has been conducted as per IS0 6892-1: 2009 standards on Shimadzu (Japan) Fully Computerized Tensile Testing Machine. Round specimen with 30mm diameter has been used for testing. Tension test results include ultimate tensile stress, proof stress and % Elongation.

 ISBN: 978-81-932074-1-3

3.3 Chemical Analysis

Chemical analysis of steel alloy samples has been carried out in order to evaluate the chemical composition of elements in test samples.

IV. RESULTS AND DISCUSSION

Mechanical properties of casted alloy samples have been evaluated by conducting hardness test, tension test, chemical analysis and corrosion test. Results of all the conducted tests have been mentioned below. Table 2 shows the hardness values of alloy steel samples in BHN as obtained from hardness test. It has been observed that hardness value has increased with varying percentage of chromium. Test results have been shown in the form of graph in Fig. 2

TABLE 2 Hardness Test Results

Sample	Sample1	Sample2	Sample3	Sample4
Hardness (BHN)	164	190	204	226

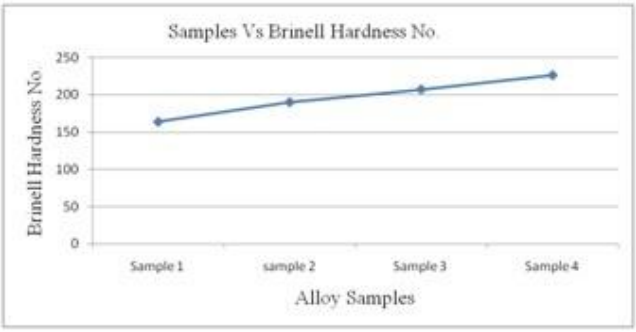
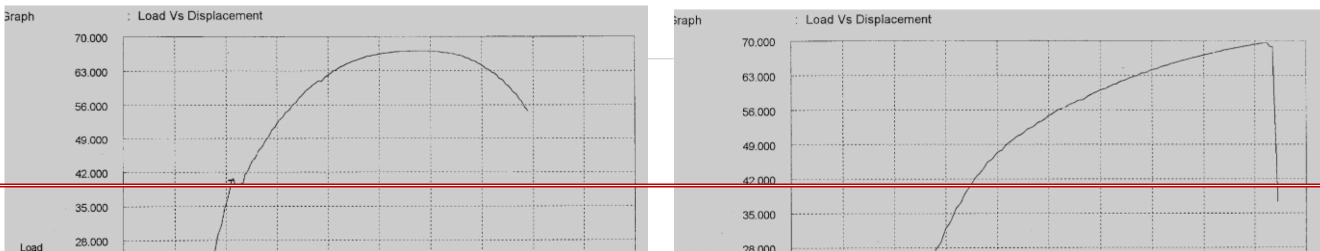


Fig.2 Graph for Alloy Samples vs. BHN

Table 3 gives tension test results for alloy steel samples. It has been observed that ultimate break load as well as ultimate stress value increases with varying percentage of chromium. Graph 2 shows tension test results in graphical form for different test samples. Figure 3 shows tension test graphs obtained in tensile test for sample 1, sample 2 and sample 3 and Sample 4 respectively.

Table 3 Tension Test Results

Sample	Sample 1	Sample 2	Sample 3	Sample4
Ultimate Break Load (kN)	67.060	69.52	82.26	94.12
Ultimate Stress (N/mm^2)	543	566	674	740



(a) **(b)**

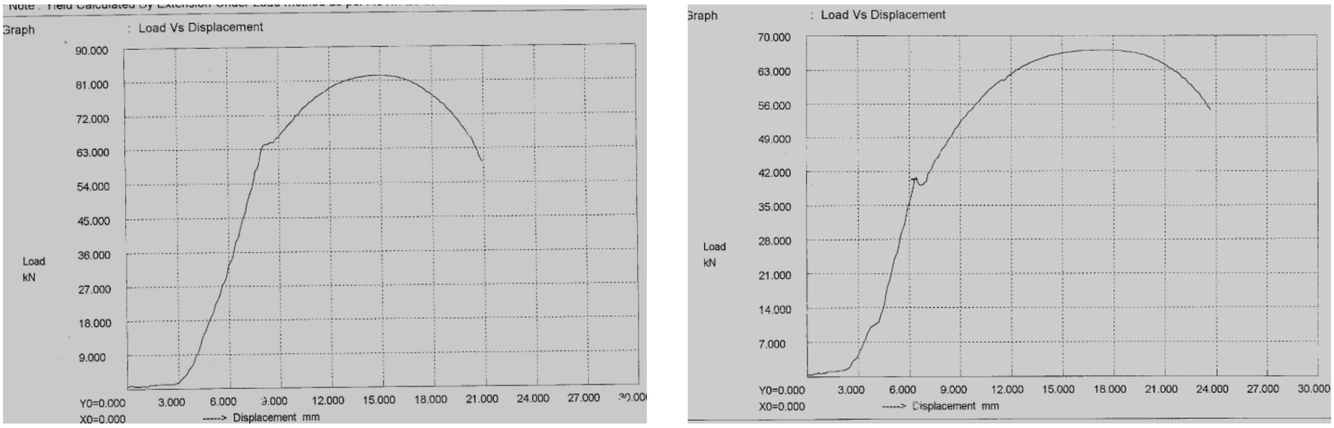
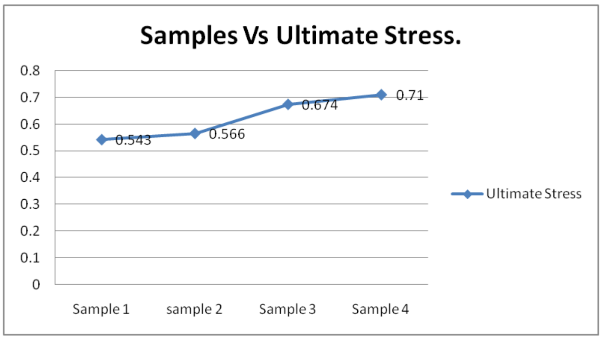


Fig. 3 Tensile Stress Graphs for (a) Sample 1 (b) Sample 2 (c) Sample 3 (d) Sample 4



Fig,4 Graph for tension strength results

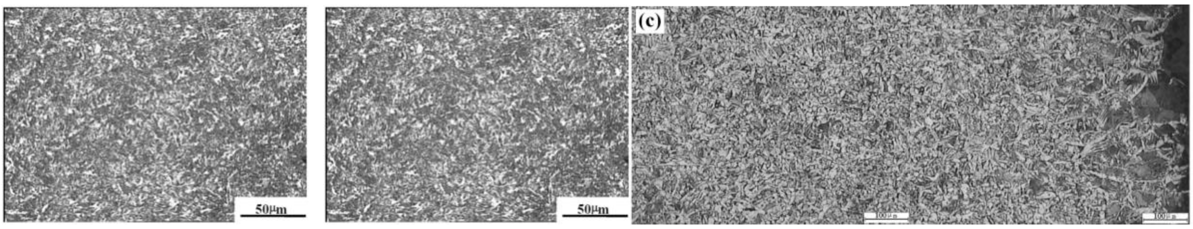
TABLE 4 Chemical Analysis of samples

Sample	Sample 1	Sample 2	Sample 3	Sample4
C	0.249	0.069	0.213	0.225
Si	0.412	0.77	0.449	0.463
Mn	0.87	0.83	0.95	0.92
Cr	4.69	9.89	14.56	19.42
Ni	0.106	9.14	0.57	0.9
Mo	0.061	2.22	0.186	1.6
Fe	93.8	79.6	84.7	78.36

Chemical analysis of alloy samples has been given in Table 4.

4.1 Microstructure Analysis

Microstructure analysis of alloy samples have been carried out by conducting IGC practice A test. Samples have been etched using Electrolytic Oxalic acid (10%) and under 500X magnification. The tests revealed that structure consists of grains of austenite having ASTM No. 5-6 and step type structure has been observed. Microstructure of alloy samples has been shown in Fig. 5.



(a) (b) (c) (d)

Fig. 5 Microstructure of Alloy samples (a) Sample 1 (b) Sample 2 (c) Sample 3 (d) Sample 4 (500X Magnification, 50 µm Scale)

V. CONCLUSION

In the present work steel alloy A487 samples with varying percentage of chromium have been prepared and tested. Following conclusions have been drawn from the work carried out

i. Chromium improved the strength of alloy as it can be seen from increasing value of tensile strength.
ii. Improvement in hardness levels due to the combined addition of Chromium has been found.
iii. Microstructure consists of grains of austenite having ASTM No.5-6 and samples have been found to be acceptable on quality standard.
iv. Increasing chromium content has not affected the strength of alloy, Tensile strength of alloy has found to be better than standard configuration. Increasing chromium content certainly enhances corrosion resistance.

VI. ACKNOWLEDGEMENT

Our thanks go to Devyani alloys Baramati for extending their help in preparation and testing of samples and Metasys Testing Lab for sample testing.

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