# Effect of Chromium and Cobalt Additions on the Corrosion Resistance of Aluminium Silicon Iron Alloy (Al-Si-Fe)

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**Abstract: Aluminium alloys are very important category of materials used for automotive, aerospace, packaging and construction due to their high mechanical properties and wide range of industrial applications. It is well known that aluminium alloys are prone to microstructural corrosion (pitting corrosion, intergranular corrosion, uniform corrosion, etc.). In this paper, the effect of addition of chromium and cobalt on the corrosion resistance of Al-Si-Fe alloy was studied. Alloying of varying percentages of chromium and cobalt from 0.1 to 0.5% with the percentages of Si, Fe, and Zn kept constant were sand cast into cylindrical test bars of 20 mm by 250 mm. The corrosion characteristics of the as-cast and age-hardened in 400 ml HCl solution at room temperature over period of 480 hrs were deduced by weight loss method. The results obtained revealed a general increase of corrosion resistance with the addition of Cr and Co with the age-hardened samples, but the rate of corrosion decreased with increase in the number of days of exposure for both as-cast and age-hardened samples. The results also indicate more steady increase of corrosion resistance for Cr up to 0.4% than Co. It was also observed that the rate of corrosion decreased with increase in the number of days of exposure for all the alloys.**

***Keywords:** Al-Si-Fe alloy, corrosion resistance, as-cast samples, age-hardened samples*

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## 1. Introduction

The deterioration of materials by corrosion can cause losses in a direct or indirect way; the direct losses are associated to the replacement costs of damaged equipments, machines, structures or parts, as well as the risks to society and environment [3], [11] and [5]. We can also add to these costs the values spent in research for more resistant corrosion materials and more effective protection methods.

According to [4] and [14], the indirect costs can be those that are consequences of the corrosion damage to parts not damaged through corrosion, such as the operation interruption of industrial plants, over dimension of structures and equipments and mainly the losses imposed to the society and the environment due to toxic or inflammable chemical accidents or leaks.

Today more than several dozens of aluminium alloys are used in different areas of manufacturing and technology (e.g., automotive, aerospace, etc.). .Aluminium and its alloys are used in many applications because of their low density, high electrical and thermal properties, durability, availability and low cost when compared with other emerging materials [10], [3]. Aluminium alloys are widely used in the production of automotive components, buildings and constructions, containers and packaging, marine, aviation, aerospace and electrical industries [2], [9], [3].

Although the influence of copper addition on the mechanical properties and corrosion resistance have been studied by many Researchers on aluminium alloys [15]. They observed addition of Cu to Al-Si-Fe to alloy system increases its susceptibility to corrosion attack in the two acidic media used (HCl and $HNO_3$) subject to a maximum of 4% Cu. The rate of corrosion in HCl is higher than in $HNO_3$ and rate of corrosion of coupon in HCl decreased with time [15]. [8] also conducted a research on the effect of Cu addition on corrosion behaviour of 7xxx series aluminium alloys. They investigated the role of Cu content, the corrosion behaviour of several AA7xxx-T6 alloys, with Cu content ranging from essentially Cu-free up to 2 wt %, in deaerated and aerated NaCl solution. Their conclusions was that, under free corrosion conditions in aerated chloride solutions, the corrosion potential increases and the polarization resistance decreases as the Cu content increases as a result of Cu enrichment on the surface, which facilitates the oxygen reduction reaction. Because of this effect, the overall influence of Cu on the corrosion behaviour is detrimental, despite the increase in breakdown potentials with Cu content.

Most of the investigations reported in the literature have focused on either high Cu content Al alloy or effect of Cu and Mn on the mechanical properties of Al alloys such as Al-Si-Fe. However, not much is known on the effect of Cr and Co on the corrosion characteristics of Al-Si-Fe alloys in the as-cast and age-hardened conditions. The main objective of this work is therefore to determine the effect of Cr and Co addition on the corrosion characteristics in 500 ml HCl solution at room temperature of Al-Si-Fe alloy system in the as-cast and age-hardened conditions.

## 2. EXPERIMENTAL TECHNIQUES

### 2.1 Materials

Materials used for this research are: high purity aluminium, ferroalloys (FeSi, FeCr, FeCo), hydrochloric acid, beakers, silica sand and bentonite. Twenty different compositions of alloys were produced with amounts of Cr and Co varied from 0 to 0.5 while the % of Si, Zn, and Fe were kept constant as observed in Table 1. These eighteen compositions were melted in a muffle resistance furnace separately in Alumina crucible and a thereafter crucibles were removed from the furnace and was followed by addition of ferroalloys. The crucibles were taken back to the furnace for half an hour and furnace temperature was raised from 750$^0$C to 800$^0$C. This was followed by addition of 0.001% potassium chloride before pouring into the mould. The cast samples were machined according to ASM standard for corrosion test specimens. Table 1 shows the chemical composition of developed alloys.

**Table 1: Chemical composition of the developed alloys**

| s/ n | % Si | %Fe | %Co | %Cr | %Zn | %Al |
|---|---|---|---|---|---|---|
| 1 | 4.3 | 0.3 | 0. | 0 | 0.01 | Bal |
| 2 | 4.3 | 0.3 | 0.1 | - | 0.01 | Bal |
| 3 | 4.3 | 0.3 | 0.2 | - | 0.01 | Bal |
| 4 | 4.3 | 0.3 | 0.3 | - | 0.01 | Bal |
| 5 | 4.3 | 0.3 | 0.4 | - | 0.01 | Bal |
| 6 | 4.3 | 0.3 | 0.5 | - | 0.01 | Bal |
| 8 | 4.3 | 0.3 | - | 0.1 | 0.01 | Bal |
| 9 | 4.3 | 0.3 | - | 0.2 | 0.01 | Bal |
| 10 | 4.3 | 0.3 | - | 0.3 | 0.01 | Bal |
| 11 | 4.3 | 0.3 | - | 0.4 | 0.01 | Bal |
| 12 | 4.3 | 0.3 | - | 0.5 | 0.01 | Bal |
| 14 | 4.3 | 0.3 | 0.1 | - | 0.01 | Bal |
| 15 | 4.3 | 0.3 | 0.2 | - | 0.01 | Bal |
| 16 | 4.3 | 0.3 | 0.3 | - | 0.01 | Bal |
| 17 | 4.3 | 0.3 | 0.4 | - | 0.01 | Bal |
| 18 | 4.3 | 0.3 | 0.5 | - | 0.01 | Bal |

### 2.2 Heat Treatment

Some of the standard corrosion coupons produced was solution heat treated at 500$^0$C in an electric furnace, soaked for 6 hrs before quenching. The quenched samples were aged hardened at 200$^0$C for 6 hrs before air cooling.

### 2.3 Corrosion test

Corrosion test was conducted based on weight loss method.

### 2.4 Weight loss measurements

The weight loss was determined by finding the difference between the original weight of the coupon and the new weight after 1 day interval. The previously weighed coupons were immersed in beakers containing 400 ml of hydrochloric acid (HCl) solution maintained at room temperature. The coupons were later retrieved at 24 hrs intervals for 20 days (480 hrs). The difference in weight was calculated as the weight loss in grams using the following relationship,

$$W = W_0 - W_1$$

This procedure of weight loss was similar to that reported previously by [7] and [3]. The corrosion rate was determined in mils per year (mpy) or millimeter per year (mm/yr) using the following relationship:

$$\text{Corrosion rate (mpy)} = KW/DAT = 534W/DAT$$

Where:

W = weight loss (mg); D = density of the material, g/cm$^3$, A = Cross sectional area, cm$^2$, $W_0$ = original weight of coupon; $W_1$ =final weight of coupon; T = exposure time; hrs, K = Constant, which is depending on the system of units used.

## 3.0 RESULTS AND DISCUSSION

### 3.1 RESULTS

The results of the effect of Co and Cr additions on the corrosion resistance of Al-Si-Mn alloy were presented in tabular and graphical form. Tables 2-7 and Figures 1-10 show the variation of corrosion rates with exposure time and percentage of Co and Cr addition for as-cast and age-hardened conditions

**Table 2.** Corrosion rate of as-cast Al-Si-Fe-Cr alloys in 400 ml HCl solution over exposure time (hrs)

| % Cr addition | Corrosion rate in mpy x $10^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 48hrs | 96hrs | 144hrs | 192hrs | 240hrs | 288hrs | 336hrs | 384hrs | 432hrs | 480hrs |
| Control | 1.174 | 0.700 | 0.540 | 0.443 | 0.382 | 0.339 | 0.332 | 0.301 | 0.277 | 0.257 |
| 0.1 | 1.088 | 0.631 | 0.517 | 0.422 | 0.372 | 0.332 | 0.323 | 0.294 | 0.271 | 0.251 |
| 0.2 | 1.090 | 0.573 | 0.472 | 0.396 | 0.355 | 0.308 | 0.309 | 0.285 | 0.262 | 0.247 |
| 0.3 | 1.159 | 0.662 | 0.534 | 0,424 | 0,375 | 0.314 | 0.306 | 0.277 | 0.255 | 0.236 |
| 0.4 | 0.855 | 0.515 | 0.424 | 0.326 | 0,298 | 0.254 | 0.277 | 0.256 | 0.240 | 0.229 |
| 0.5 | 0.726 | 0.511 | 0.430 | 0.344 | 0.299 | 0.262 | 0.276 | 0.251 | 0.234 | 0.220 |

**Table 3.** Corrosion rate of aged-hardened Al-Si-Fe-Cr alloys in 400 ml HCl solution over exposure time (hrs)

| % Cr addition | **Corrosion rate mpy x $10^3$** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **48hrs** | **96hrs** | **144hrs** | **192hrs** | **240hrs** | **288hrs** | **336hrs** | **384hrs** | **432hrs** | **480hrs** |
| Control | 1.451 | 0.831 | 0.592 | 0.450 | 0.380 | 0.325 | 0.287 | 0.259 | 0.235 | 0.216 |
| 0.1 | 1.212 | 0.658 | 0.508 | 0.384 | 0.316 | 0.264 | 0.264 | 0.242 | 0.222 | 0.211 |
| 0.2 | 1.322 | 0/725 | 0.539 | 0.420 | 0.351 | 0.304 | 0.270 | 0.242 | 0.225 | 0.208 |
| 0.3 | 1.258 | 0.745 | 0.540 | 0.420 | 0.349 | 0.302 | 0.267 | 0.242 | 0.220 | 0.203 |
| 0.4 | 0.919 | 0.501 | 0.398 | 0.319 | 0.288 | 0.246 | 0.249 | 0.227 | 0.209 | 0.195 |
| 0.5 | 0.833 | 0.480 | 0.394 | 0.312 | 0.287 | 0.244 | 0.240 | 0.226 | 0.08 | 0.195 |

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**Table 4.** Corrosion rate of as-cast Al-Si-Fe-Co alloys in 400 ml HCl over exposure time (hrs)

| % Co addition | Corrosion rate mpy x $10^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **48hrs** | **96hrs** | **144hrs** | **192hrs** | **240hrs** | **288hrs** | **336hrs** | **384hrs** | **432hrs** | **480hrs** |
| Control | 1.174 | 0.700 | 0.540 | 0.443 | 0.392 | 0.339 | 0.332 | 0.301 | 0.277 | 0.257 |
| 0.1 | 1.304 | 0.716 | 0.577 | 0.454 | 0.396 | 0.351 | 0.316 | 0.291 | 0.269 | 0.249 |
| 0.2 | 1.174 | 0.591 | 0.493 | 0.383 | 0.341 | 0.303 | 0.311 | 0.287 | 0.264 | 0.246 |
| 0.3 | 1.295 | 0.815 | 0.597 | 0.469 | 0.399 | 0.347 | 0.311 | 0.284 | 0.259 | 0.241 |
| 0.4 | 1.304 | 0.716 | 0.577 | 0.454 | 0.380 | 0.332 | 0.296 | 0.269 | 0.252 | 0.231 |
| 0.5 | 1.056 | 0.625 | 0.579 | 0.397 | 0.341 | 0.301 | 0.288 | 0.258 | 0.151 | 0.217 |

**Table 5.** Corrosion rate of aged-hardened Al-Si-Fe-Co alloys in 400 ml HCl solution over exposure time (hrs)

| % Co addition | Corrosion rate mpy x $10^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **48hrs** | **96hrs** | **144hrs** | **192hrs** | **240hrs** | **288hrs** | **336hrs** | **384hrs** | **432hrs** | **480hrs** |
| Control | 1.451 | 0.831 | 0.592 | 0.450 | 0.380 | 0.325 | 0.287 | 0.259 | 0.235 | 0.216 |
| 0.1 | 1.264 | 0.805 | 0.571 | 0.447 | 0.373 | 0.321 | 0.285 | 0.357 | 0.233 | 0.215 |
| 0.2 | 1.188 | 0.734 | 0.555 | 0.442 | 0.357 | 0.309 | 0.281 | 0.254 | 0.227 | 0.209 |
| 0.3 | 0.955 | 0.571 | 0.446 | 0.347 | 0.307 | 0.258 | 0.265 | 0.240 | 0.219 | 0.207 |
| 0.4 | 1.285 | 0.710 | 0.509 | 0.398 | 0.334 | 0.290 | 0.259 | 0.235 | 0.215 | 0.200 |
| 0.5 | 1.256 | 0.648 | 0.507 | 0.394 | 0.336 | 0.286 | 0.254 | 0.232 | 0.210 | 0.194 |

**Table 6**. Corrosion rate of as-cast Al-Si-Fe-Cr-Co alloys in 400 ml HCl solution over exposure time (hrs)

| % Cr-Co addition | **Corrosion rate in mpy x $10^3$** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **48hrs** | **96hrs** | **144hrs** | **192hrs** | **240hrs** | **288hrs** | **336hrs** | **384hrs** | **432hrs** | **480hrs** |
| Control | 1.174 | 0.700 | 0.540 | 0.443 | 0.392 | 0.339 | 0.332 | 0.301 | 0.277 | 0.257 |
| 0.1Cr-0.1Co | 1.329 | 0.803 | 0.607 | 0.480 | 0.405 | 0.364 | 0.317 | 0.291 | 0.416 | 0.248 |
| 0.2Cr-0.2Co | 1.307 | 0.747 | 0.577 | 0.454 | 0.387 | 0.336 | 0.304 | 0.279 | 0.258 | 0.241 |
| 0.3Cr-0.3Co | 1.292 | 0.722 | 0.567 | 0.487 | 0.396 | 0.343 | 0.306 | 0.277 | 0.251 | 0.233 |
| 0.4Cr-0.4Co | 1.196 | 0.601 | 0.404 | 0.333 | 0.294 | 0.253 | 0.269 | 0.248 | 0.230 | 0.216 |
| 0.5Cr-0.5Co | 1.044 | 0.515 | 0.424 | 0.326 | 0.340 | 0.289 | 0.283 | 0.256 | 0.233 | 0.217 |

Table 7. Corrosion rate of aged-hardened Al-Si-Fe-CrCo alloys in 400 ml HCl solution over exposure time (hrs)

| % CrCo addition | **Corrosion rate mpy x $10^3$** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **48hrs** | **96hrs** | **144hrs** | **192hrs** | **240hrs** | **288hrs** | **336hrs** | **384hrs** | **432hrs** | **480hrs** |
| Control | 1.451 | 0.831 | 0.592 | 0.450 | 0.380 | 0.325 | 0.287 | 0.259 | 0.235 | 0.216 |
| 0.1Cr-0.1Co | 1.257 | 0.772 | 0.542 | 0.426 | 0.356 | 0.308 | 0.275 | 0.251 | 0.229 | 0.211 |
| 0.2Cr-0.2Co | 1.212 | 0.684 | 0.508 | 0.396 | 0.336 | 0.297 | 0.265 | 0.245 | 0.225 | 0.208 |
| 0.3Cr-0.3Co | 1.343 | 0.783 | 0.546 | 0.424 | 0.351 | 0.301 | 0.265 | 0.238 | 0.216 | 0.203 |
| 0.4Cr-0.4Co | 1.239 | 0.766 | 0.533 | 0.416 | 0.342 | 0.296 | 0.258 | 0.233 | 0.210 | 0,194 |
| 0.5Cr-0.5Co | 0.863 | 0.491 | 0.428 | 0.342 | 0.293 | 0.259 | 0.235 | 0.215 | 0.196 | 0.184 |

## 3.2 DISCUSSION

As it has been observed from the results that were obtained in this research work, the corrosion rate decreases for both As-cast and Age-hardened alloy with increase of amount of Cr and Co. However, the Age-hardened alloy possessed better corrosion resistance than as-cast alloys. The reason for low corrosion rate of age-hardened alloys might be due to the precipitation of the intermetallic compounds and the amount of intermetallic precipitated increases with increase of Cr and Co contents.

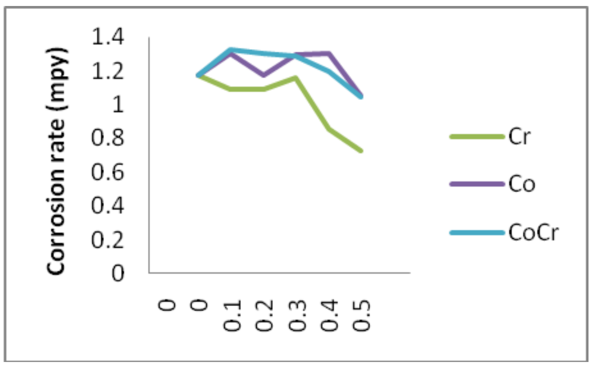


**Fig.1**. Corrosion rate versus % of alloying additives in 400 ml HCl solution for as-cast condition after two days exposure time

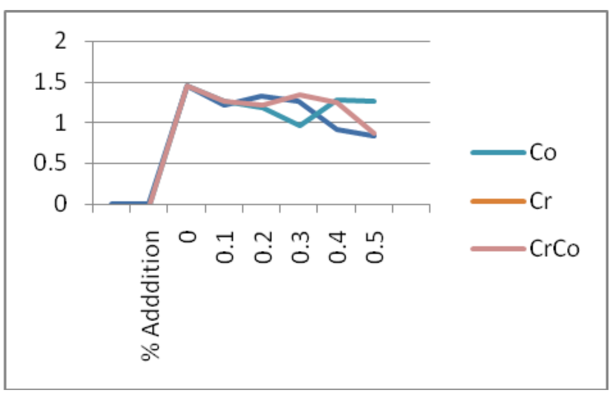


**Fig.2.** Corrosion rate versus % of alloying additives in 400 ml HCl solution for aged-hardened condition after two days exposure time

Figures 1- 4 have shown that with simultaneous addition of Cr and Co to the alloy system, it impacted the highest corrosion resistance to the alloy due to the formation of hard and passive phases that acted as strong protective barriers to corrosion. Figures 5 to 10 showed that after 480 hrs exposures, 0.5% (Cr, Co and CoCr) alloys have the best corrosion resistance for both as-cast and aged-hardened conditions. Figures 1-4 showed the rate of corrosion decreasing with increase of percentage of Cr, Co and CrCo for both as-cast and age-hardened conditions.

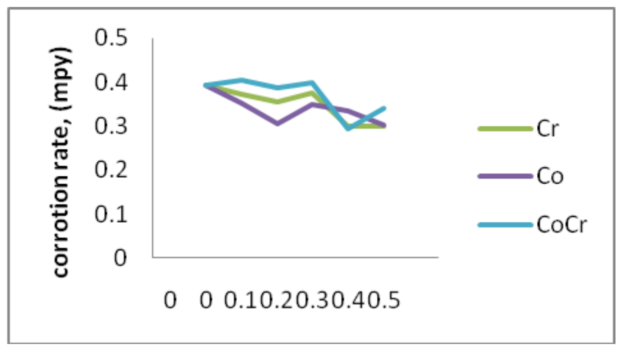


**Fig.3.** Corrosion rate versus % of alloying additives in 400 ml HCl solution for as- cast condition after 10 days exposure time.

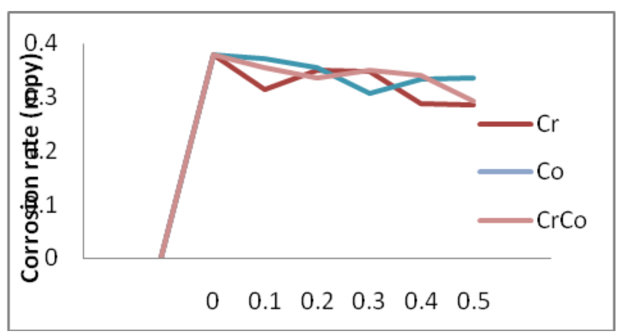


**Fig. 4** Corrosion rate versus % of alloying additives in 400 ml HCl solution for aged-hardened condition after 10 days exposure time

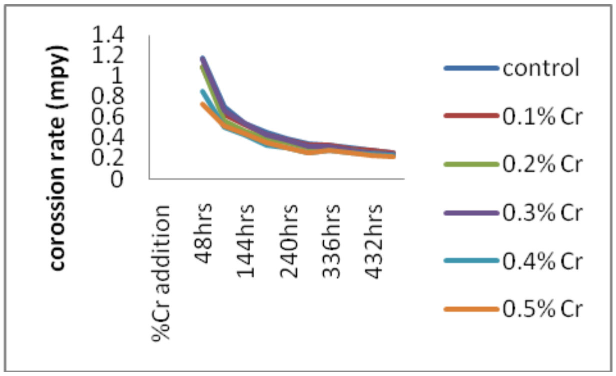


**Fig.5.** Corrosion rate vs. Time of Exposure (hrs) for Cr additions in the As-cast condition

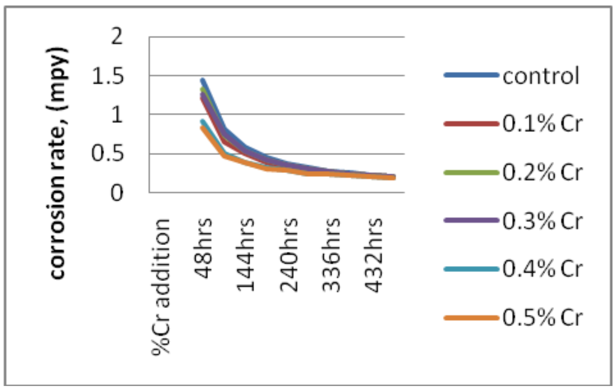


**Fig 6.** Corrosion rate of aged-hardened Al-Si-Fe-Cr alloys in 400 ml HCl over the exposure time (hrs)

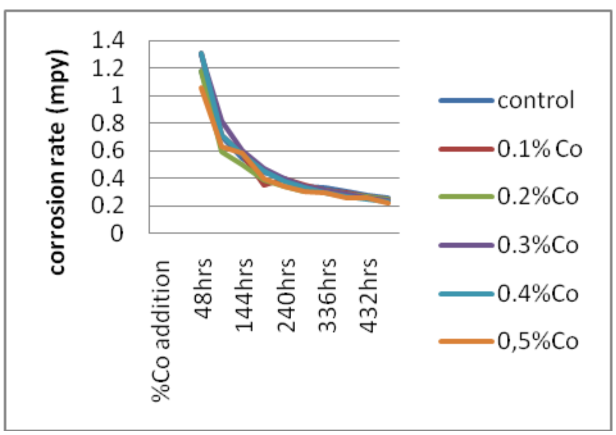


**Fig.7.** Corrosion rate of as-cast Al-Si-Fe-Co alloys in 400 ml HCl over the exposure time (hrs).

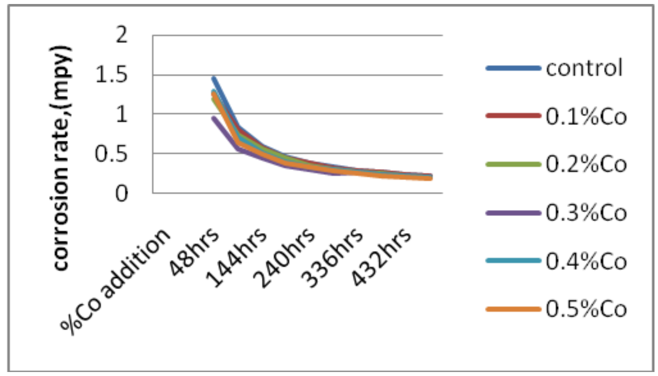


**Fig.8.** Corrosion rate of aged-hardened Al-Si-Fe-Co alloys in 400 ml HCl solution over the exposure time (hrs)

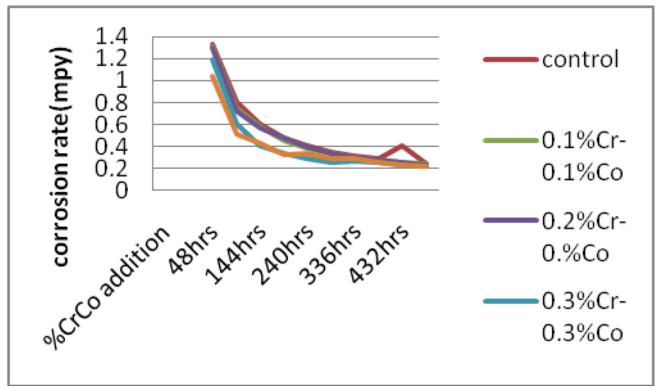


**Fig.9** Corrosion rate of as-cast Al-Si-Fe-CoCr alloys in 400 ml HCl solution over the exposure time (hrs)

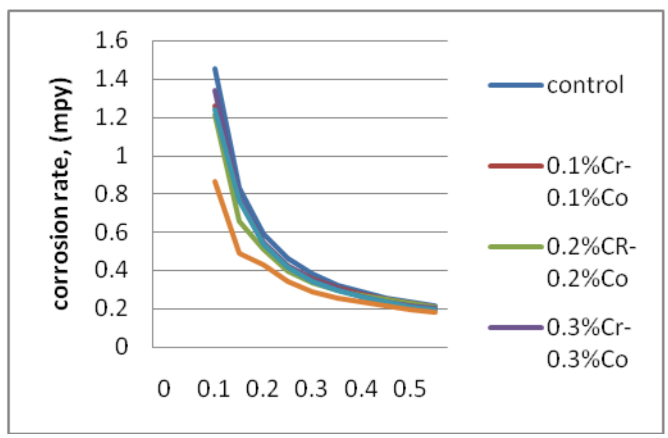


**Fig.10.** Corrosion rate of aged-hardened Al-Si-Fe-CoCr alloys in 400 ml HCl solution over the exposure time (hrs).

**4. Conclusions:**

The results from this work have clearly explained the following facts:

- There was a general increase of corrosion resistance with increase of Co and Cr in the aged-hardened condition than as-cast condition.
- Addition of Cr and Co separately and CrCo simultaneously to Al-Si-Fe alloy improved the corrosion resistance in both as-cast and aged-hardened conditions subject to a maximum of 0.5% (Cr and Co) addition.

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