EFFECT OF SCANDIUM ADDITION ON THE EROSION CORROSION BEHAVIOUR OF AA7075

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Abstract

In this study, 0.2wt.% Scandium has been added to the 7075 aluminium alloy through stir casting technique to obtain 10 mm thick plates. Erosion corrosion studies have been conducted on the as-cast scandium added AA7075 plates as well on the as-cast AA7075 plates and their response has been studied. Experiments were designed using Taguchi's orthogonal arrays. Erosion corrosion parameters that are considered for this study are slurry flow rate, percent sand content in the slurry and pH value of the slurry, each at three different levels. Effect of each parameter on the rate of erosion corrosion measured using weight loss method has been studied by conducting analysis of variance. Study revealed the scandium added AA7075 has better resistance to erosion corrosion. Analysis of variance revealed that slurry flow rate is the dominant parameter controlling the rate of erosion corrosion, where as sand content also plays an important role while pH value of the slurry is not a significant parameter.

Key words: Flow Rate, Taguchi method, Anova, Macrostructure.

INTRODUCTION

The 7075 Aluminium alloy is used on the structure and outer body of airplanes, faces the repetitive high speed bombardment of solid particles, fluid and dust which can cause the material to have erosion, raising the surface irregularity and sometimes surface cracking. Aluminium that contains scandium has been shown to have excellent mechanical properties and corrosion properties at room temperature due to the presence of very fine and coherent Al_3Sc precipitates, which can be effective obstacles to mobile dislocations. Scandium also stabilizes fine grain microstructures at higher temperature. In addition, Sc also effectively reduces hot tearing susceptibility and increases corrosion resistance in the high strength aluminium alloys [2-3]. Erosion corrosion encompasses a wide range of flow induced corrosion processes. Flowing fluids can damage protective films on metals resulting in higher corrosion rate. Damage to the films may be the result of mechanical forces and accelerated corrosion may be accompanied by erosion of the underlying metal [4].

The combined effects of erosion - corrosion can be significantly higher than the sum of the effects of the processes acting separately. There have been many studies done to understanding the pure corrosion and pure Erosion mechanisms. [5-6]. However, little knowledge exists in understanding erosion corrosion behaviour and mechanisms. It is agreed that impinging particles remove deposits or the protective layer on the material surface resulting in continuous exposure of fresh material surface to the corrosive environment resulting in higher corrosion rates. In 7075 Aluminium alloy, the Aluminium oxide dissolves in some chemicals, notably strong acids and alkalis. When the film is removed, the metal corrodes rapidly by uniform dissolution. Generally the oxide film is stable over a pH range of about 4.0 - 9.0, but there are exceptions, such as stability in concentrated nitric acid (pH 1) and concentrated ammonium hydroxide (pH 13).[7].

The Taguchi method is a very useful technique that provides a systematic and economical methodology for process optimization and this is an important tool for the design of high quality systems. Taguchi approach to DOE (design of experiments) in easy to adopt and apply for users with minimum knowledge of statistics, hence gained wide reputation in the engineering and scientific community. This is a scientific methodology for obtaining product and process condition, which are minimum sensitive to the various causes of variation, and which produce very high-quality products with low manufacturing costs [8]. In this study, the role of the Taguchi technique used to set the limits of erosion corrosion process parameters with the optimal weight loss is reported.

Design of experiment

Design of Experiment is one of the essential and powerful statistical techniques used to study the effect of many variables simultaneously and involves a series of steps which must follow some sequence for the experiment to yield an improved understanding of process performance. All designed experiments require a certain number of combinations of factors and levels be tested in order to find out the results of those test conditions [9]. The Taguchi approach enables a complete understanding of the individual and combined from a minimum number of simulation trials. This technique is multi - step process which follow a certain sequence for the experiments to yield an improved understanding of product or process performance. [10-11].

The objective of this study is to determine the optimal settings of erosion corrosion process parameters using Taguchi's experimental design method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) are employed to find the optimal levels.

Materials and Methods

In this study two types of alloy casting done by using stir casting technique.

- 7075 Aluminium alloy
- 7075 Aluminium alloy with 0.2 wt.% of scandium

The chemical composition of AA7075 and AA7075 with 0.2wt.% Sc shown in table 1. In order to carry out erosion corrosion experiments, alloy specimens of $25 \times 15 \times 5$ mm size were cut by using band saw machine. Specimens were mechanically polished successively using emery papers of different grit size and then completely washed with distilled water, finally specimens were cleaned with acetone.

The Erosion corrosion tests were conducted using an Erosion testing machine shown in figure 1. Diameter of nozzle is 5mm, Slurry is prepared by mixing of water and abrasive particles (Sand), Size of the sand approximately 100 microns. The chemical composition of sand is SiO_2 - 98%, Al_2O_3 - 1.5%, Fe_2O_3 - 0.5% and very small amount of P_2O_5. Each erosion-corrosion test is carried out for a fixed time span 90 minutes. Mixing ratios of the slurry are,

- 10 litre of water - 500 grams of sand (5.% of sand)
- 10 litre of water - 1000 grams of sand (10.% of sand)
- 10 litre of water - 1500 grams of sand (15.% of sand)

PLAN OF EXPERIMENTS

The steps applied for Taguchi optimization in this study are as follows.

- Set erosion corrosion process parameters
- Select Taguchi orthogonal array
- Conduct Experiments
- Weight loss measurements
- Analyze results by Signal to noise ratio
- Predict optimum (maximum) performance
- Confirmation experiment

In this study, three process parameters and their levels were set for erosion corrosion experiment. The process parameters are flow rate of slurry, pH value of slurry and percentage of sand in slurry, each at three different levels. The value of the erosion – corrosion process parameters and their levels were listed in Table 2. The degrees of freedom for three parameters were calculated as follows.

Degree of Freedom (DOF) = number of levels −1. For each factor, DOF equal to: For (flow rate); DOF = 3 – 1 = 2; For (pH value); DOF = 3 – 1 = 2; For (percentage of sand); DOF = 3 – 1 = 2

In this study nine experiments were conducted for three parameters each at three levels. For this Taguchi L9 orthogonal array was used, which has nine rows and three columns for conducting nine erosion corrosion experiments. L9 orthogonal array has eight Degree of freedom, in which 6 Degree of freedom were assigned to three factors (each parameter have 2 Degree of freedom) and 2 Degree of freedom was assigned to the error. According to the rule that Degree Of Freedom (DOF) for an orthogonal array should be greater than or equal to sum of those erosion corrosion parameters, a L9 (3^3)Orthogonal array which has 9 rows and 3 columns were selected as shown in Table 3.

Taguchi recommends the use of the S/N ratio for the determination of the quality characteristics implemented in engineering design problems. In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on the response variable. In this way, the optimal levels of erosion corrosion process parameters can be estimated.

Results and Discussion

The experiments were conducted as per L9 orthogonal array and the weight loss results obtained for various combinations of erosion corrosion parameters were shown in Table 4 and 5. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 16. The S/N ratio values obtained for the erosion corrosion experiments in AA7075 and AA7075-0.2%Sc are as shown in table 4 and table 5 respectively.

Analysis of the S/N Ratio

Taguchi method uses the signal - to - noise (S/N) ratio, because it minimizes quality characteristic variation due to uncontrollable parameter. The maximum weight loss is the objective function so that "the larger-the-better" S/N ratio is chosen. The S/N ratio for the larger-the-better is

$$S/N = -10 * \log \text{(mean square deviation)} \text{ ------ } (1)$$

$$S/N = -10 \log 1/n\ (\Sigma 1/y^2) \text{ ------- } (2)$$

Where n is the number of measurements in a trial / row, and y is the measured value in a run / row. The Signal to Noise ratio values are calculated by taking into consideration eqn. 2.

Regardless of the category of the performance characteristics, a greater Signal to noise ratio (S/N ratio) value corresponds to a better performance. Therefore, the optimal level of the erosion corrosion parameters is the level with the greatest S/N value. The response table for the flow rate, pH value and percentage of sand was created in the integrated manner and the results are given in table 6 and 7.

Based on the analysis of the Signal to noise ratio in AA7075 and AA7075-0.2%Sc, the optimal (maximum) erosion corrosion performance were obtained at 15 l/min flow rate (level 3), 10 pH in pH value (level 3) and 15 percentage of sand (level 3). Fig. 2 and Fig. 3 shows the main effects of the process parameters on the flow rate, pH value and percentage of sand in AA7075 and AA7075-0.2%Sc respectively.

Analysis of variance (ANOVA)

Analysis of Variance (ANOVA) is a computational technique to quantitatively estimate the relative contribution, which each controlled erosion corrosion parameter makes to the overall measured response and expressing it as a percentage. Statistically, there is a tool called as F-test, named after Fisher [11], to see which design process parameters have a significant effect on the quality characteristic. In the analysis, the F-ratio is commonly used to determine the significance of a factor.

ANOVA was used to determine the design parameters significantly influencing the weight loss (response). Table 7 and 8 shows the results of ANOVA for AA7075 and AA7075 – 0.2%Sc respectively. The last column of Table 7 shows the percentage of contribution of each parameter on the response (weight loss), indicating the percentage of influence on the result. It has been observed from the results obtained for AA7075, the flow rate was the most significant parameter having the highest statistical influence (82.71%) on the weight loss of the material, followed by Percentage of sand (13.63%) and pH value (3.06%). AA7075 – 0.2%Sc was highly influenced by flow rate (80.22%), Percentage of sand (14.79%) and pH value (4.26%). From this analysis, flow rate, pH value, Percentage of sand are identified as having significant effects on the output (weight loss) in AA7075 and AA7075 – 0.2%Sc.

Confirmation Test

The experimental confirmation test is final step in verifying the results drawn based on Taguchi method. It is used to find the maximum weight loss in erosion corrosion experiments. The confirmation tests were performed by setting the optimum (maximum) condition of the three factors such as 10pH for pH value, 15 l/min for flow rate and 15% of sand were shown in table 9. The weight loss was found in AA7075 is 0.1169 grams and AA 7075 – 0.2%Sc is 0.0986 grams in the confirmation test.

Hardness, Microstructure and Macrostructure;

The hardness tests were carried out according to ASTM E384-11e1 standards using Vickers hardness testing machine with a pyramidal diamond indenter of 0.5 kg load for 15 seconds. The test was conducted at room temperature and the measurement of hardness was taken at ten different places on each sample to obtain an average value of hardness. Hardness of the as-cast AA7075 and as-cast AA7075 – 0.2wt.% Sc are 101 VHN and 114 VHN respectively.

Microstructure of the as-cast AA7075 and as-cast AA7075 – 0.2%Sc were shown in Figure 4 and figure 5 respectively. Scandium added 7075 aluminium alloy shows the eqiaxied dendritic structure, the primary Al_3Sc phase forms in the center of alloy grains, acts as heterogeneous nuclei in the melt and leads to the grain refinement of the alloy.

Macrostructure of the 7075 aluminium alloy and scandium added 7075 aluminium alloy were shown in Figure 4(a&b) and figure 5(a&b) respectively. In Fig (4a&5a) clearly shows the very low erosion corrosion behaviour of the material and the parameters are 9 l/min for flow rate, 7 pH for pH value and 10% of sand. In Fig (4b&5b) shows the high erosion corrosion behaviour, AA7075 has more erosion corrosion (weight loss) than the AA7075 – 0.2% Sc. The maximum erosion corrosion parameters are, 15 l/min for flow rate, 10 pH for pH value and 15 % of sand.

Conclusion

In this study Taguchi method used for investigating the effects of erosion corrosion process parameters on the weight loss in 7075 Aluminium alloy and scandium added 7075 aluminium alloy. From the analysis of the results using the conceptual signal-to-noise (S/N) ratio approach, analysis of variance (ANOVA), and Taguchi's optimization method, considering the results, the conclusions of this study are as follows:

- Micro-structures clearly show the finer eqiaxed grains in scandium added 7075 Aluminium Alloy.
- Flow Rate (82.71%) has the highest influence on weight loss followed by Sand (13.63%) and pH value (3.06%) for 7075 Aluminium alloy.
- Flow Rate (80.22%) has the highest influence on weight loss followed by Sand (14.79%) and pH value (4.26%) for 0.2wt.% scandium added 7075 Aluminium alloy.
- The maximum weight loss for AA7075 is 0.1169 grams and AA 7075 – 0.2wt.% Sc is 0.0986 grams in the confirmation test.
- Scandium added 7075 aluminium alloy has exhibited better resistance erosion corrosion than the 7075 aluminium alloy.

REFERENCES

1. H.M. Clark(1991), On the impact rate and impact energy of particles in a slurry pot erosion tester, Wear - 147, pp.165-183.

2. Filatov Y A, Yelagin V I, Zakharov, V V ."New Al-Mg-Sc Alloys[J]" Mater Sci Eng A , 2000, A280: pp 97-101

3. Jeoung Han Kim1, Jong Taek Yeom1, Jae Keun Hong, Sung Yong Shim, Su Gun Lim, Nho Kwang Park, “Effect of Scandium on the Hot extrudability of 7075 Aluminium Alloy,” Met. Mater. Int., Vol - 16, No.- 4 in (2010), pp. 669~677

4. ASTM G 15-97. “Standard terminology relating to corrosion and corrosion testing,” Annual book of ASTM standards, vol. 03.02: metal corrosion, west conshohocken, PA, 1997, pp. 65-69.

5. Kermani M. B. and Morshed A., “carbon dioxide corrosion in oil and gas production-a compendium,” Corrosion(2003), Vol.(59), No. 8, page no. 659-660

6. Alan L.V., “Solid particle erosion and erosion-corrosion of materials,” ASM INTERNATIONAL, c- (1995)

7. John E. Hatch., “Aluminium properties and physical metallurgy” ASM INTERNATIONAL, c 1984, pp 242-245.

8. Ross, P.J. 1988," Taguchi Techniques for Quality Engineering", McGraw-Hill, New York.

9. Taguchi.G and Konishi, S., (1987), “Taguchi methods, orthogonal arrays and linear graphs, tools for quality engineering”, Dearborn, MI, American supplier Institute, pp.34-38.

10. Taguchi G., “Taguchi on robust technology development methods”. New York, NY: ASME press, 1993, p. 1-50.

11. Ross P. J., "Taguchi technique for quality engineering",. McGRAW- Hill International Editions, Singapore, (1996).

12. R.A. Fisher(1925), “Statistical Methods for Research Worker”, Oliver & Boyd, London.

13. Bendell, J. Disney, W.A. Pridmore - (1989), “Taguchi Methods: Applications in World Industry, IFS Publications”, UK.

14. H.M. Clark(1993), Specimen diameter, impact velocity, erosion rate and particle density in a slurry pot erosion tester, Wear 162-164 in 1993, pp.669-678.

ALLOY	Mg	Si	Cu	Mn	Cr	Zn	Fe	Sc	Al
AA7075	2.8	0.30	1.5	0.29	0.25	6	0.39	-	Balance
AA7075 - 0.2%Sc	2.8	0.30	1.5	0.29	0.25	6	0.39	0.2	Balance

Table 1: Chemical composition of the experimental alloys (wt. %)

Symbol	Process Parameter	Unit	Level 1	Level 2	Level 3
P	pH Value	pH	4	7	10
F	Flow Rate	l/min	12	15	18
S	Percentage of Sand	%	5	10	15

Table 2: Erosion corrosion Process parameters and their levels

Exp No	pH Value (pH)	Flow Rate (l/min)	Percentage of Sand (%)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3: Orthogonal array L_9 (3^3) of Taguchi Method

Exp No	pH Value (pH)	Flow Rate (l/min)	Percentage of Sand (%)	Weight Loss (grams)	S/N Ratio
1	4	9	5	0.0182	−34.7986
2	4	12	10	0.0198	−34.0667
3	4	15	15	0.0643	−23.8358
4	7	9	10	0.0035	−49.1186
5	7	12	15	0.0323	−29.8159
6	7	15	5	0.0475	−26.4661
7	10	9	15	0.0265	−31.5351
8	10	12	5	0.0228	−31.7676
9	10	15	10	0.0519	−25.6967

Table 4: Experimental results and S/N ratio for AA7075

Exp No	pH Value (pH)	Flow Rate (l/min)	Percentage of Sand (%)	Weight Loss (grams)	S/N Ratio
1	4	9	5	0.0142	-36.9542
2	4	12	10	0.0171	-35.3401
3	4	15	15	0.0579	-24.7464
4	7	9	10	0.0021	-53.5556
5	7	12	15	0.0285	-30.9031
6	7	15	5	0.0387	-28.2458
7	10	9	15	0.0224	-32.9950
8	10	12	5	0.0237	-32.5050
9	10	15	10	0.0455	-26.8398

Table 5: Experimental results and S/N ratio for AA7075 - 0.2%Sc

Symbol	Parameter	Level 1	Level 2	Level 3	Rank
P	pH Value (pH)	-30.90	-35.13	**-29.67**	3
F	Flow Rate (l/min)	-38.48	-32.88	**-25.33**	1
S	Percentage of Sand (%)	-31.01	-36.29	**-28.40**	2

Table 6: Response Table for Signal to Noise ratios - Larger is better for AA7075

Symbol	Parameter	Level 1	Level 2	Level 3	Rank
P	pH Value (pH)	−32.35	−37.57	**−30.78**	3
F	Flow Rate (l/min)	−41.17	−32.92	**−26.61**	1
S	Percentage of Sand (%)	−32.57	−38.58	**−29.55**	2

Table 7: Response Table for Signal to Noise ratios – Larger is better for AA7075 – 0.2%Sc

Symbol	Parameter	Degrees of Freedom	Sum of Square	Mean Square	F ratio	Percentage of contribution
P	pH Value (pH)	2	0.0000890	0.0000445	5.29	3.06
F	Flow Rate (l/min)	2	0.0023982	0.0011991	142.52	82.71
P	Percentage of Sand (%)	2	0.0003954	0.0001977	23.50	13.63
Error		2	0.0000168	0.0000084		0.58
Total		8	0.0028995			

Table 7: Results of ANOVA for the erosion corrosion behaviour (AA7075)

Symbol	Parameter	Degrees of Freedom	Sum of Square	Mean Square	F ratio	Percentage of contribution
P	pH Value (pH)	2	0.0000999	0.0000499	5.97	4.26
F	Flow Rate (l/min)	2	0.0018809	0.0009404	112.48	80.22
S	Percentage of Sand (%)	2	0.0003470	0.0001735	20.75	14.79
Error		2	0.0000167	0.0000084		0.71
Total		8	0.0023445			

Table 8: Results of ANOVA for the erosion corrosion behaviour (AA7075 – 0.2%Sc)

pH Value (pH)	Flow Rate (l/min)	Percentage of Sand (%)	As-cast AA7075 Weight Loss (grams)	As-cast AA7075 – 0.2%Sc Weight Loss (grams)
10	15	15	0.1169	0.0986

Table 9: Confirmation test for AA7075 and AA7075 – 0.2%Sc

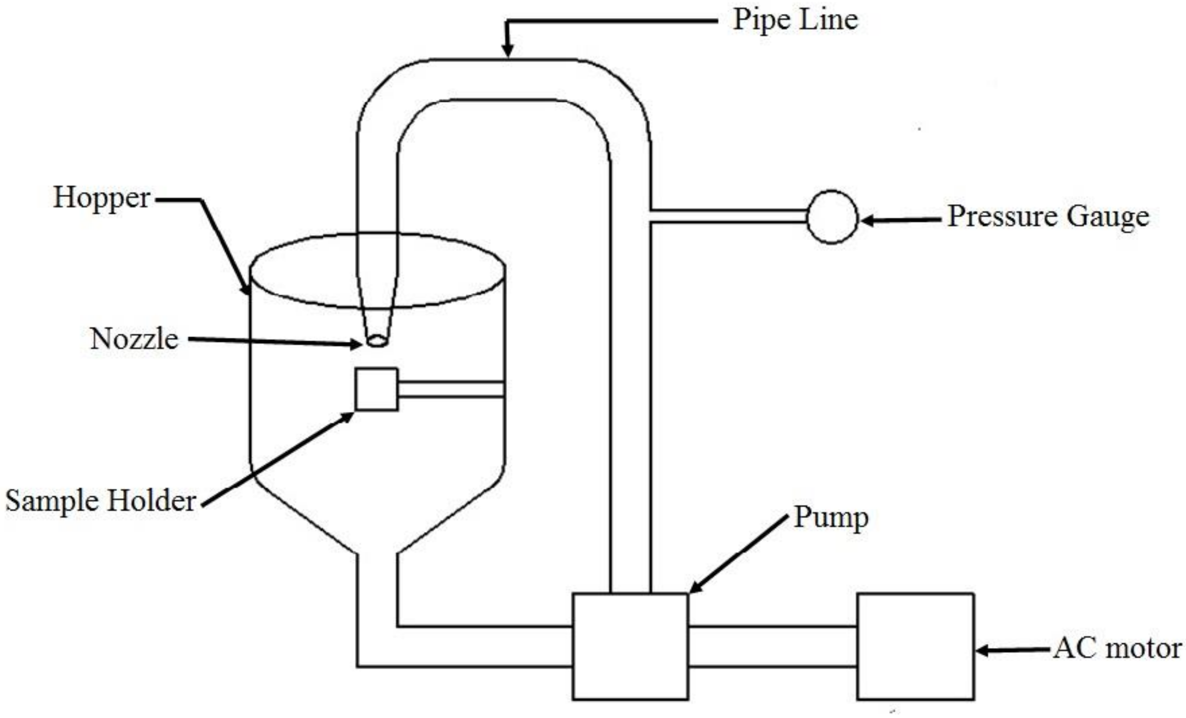

Fig 1. Erosion Corrosion Machine

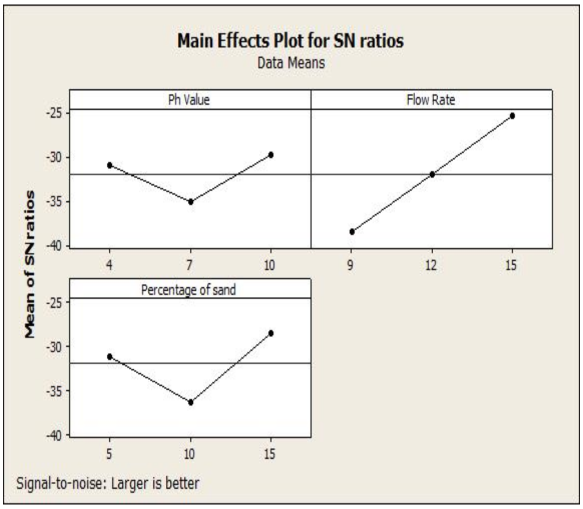

Fig 2: Main Effects Plot for SN ratios (AA7075)

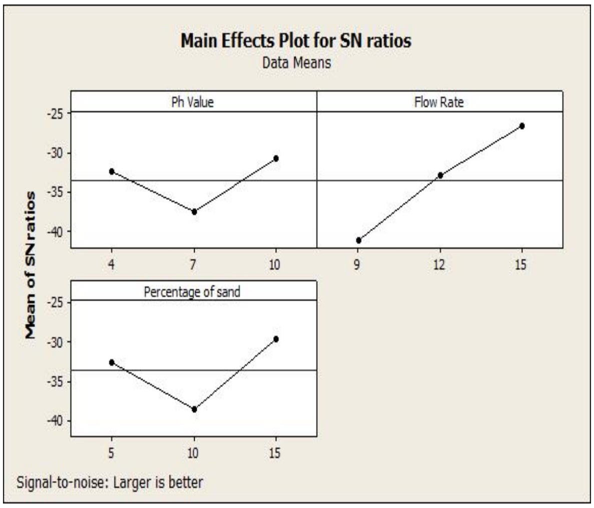

Fig 3: Main Effects Plot for SN ratios (AA7075 - 0.2%Sc)

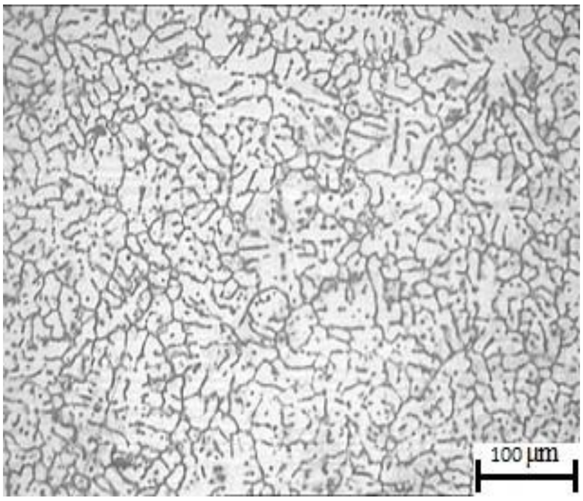

Fig 4: As-Cast (AA 7075)

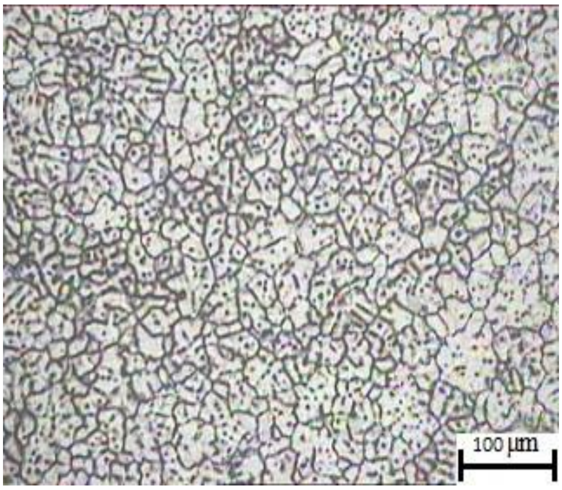

Fig 5: As-Cast (AA 7075 – 0.2%Sc)

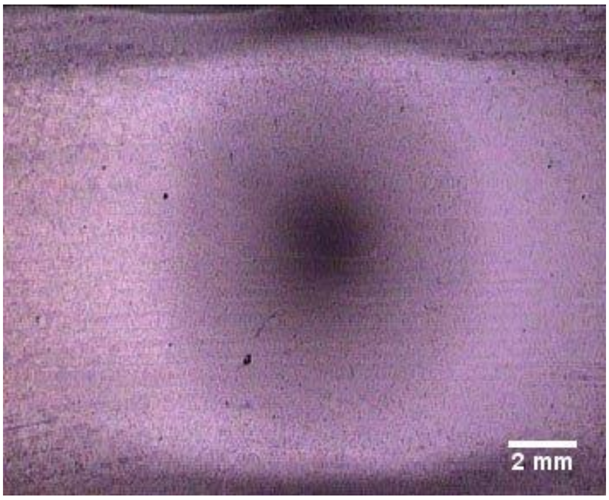

Fig 4a: Low erosion corrosion behaviour of AA7075 (7pH for pH value, 9 l/min for flow rate and 10% of sand)

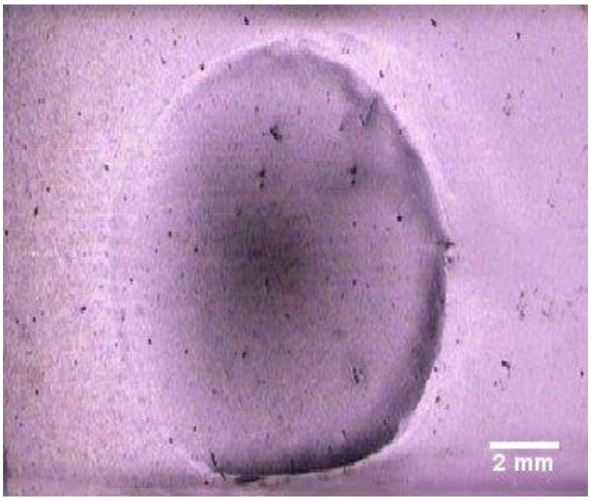

Fig 4b: High erosion corrosion behaviour of AA7075 (10pH for pH value, 15 l/min for flow rate and 15% of sand)

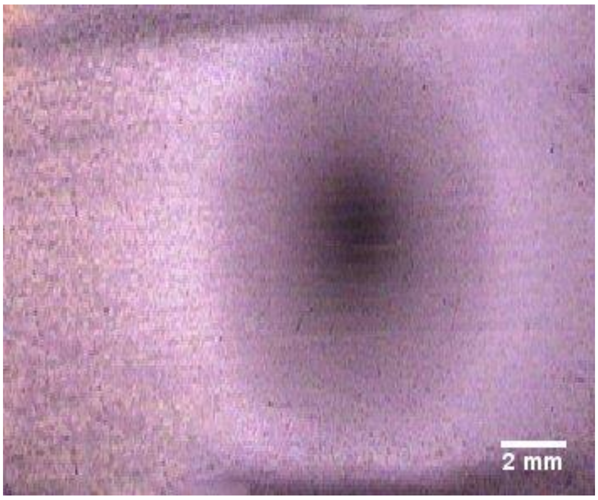

Fig 5a: Low erosion corrosion behaviour of AA7075 – 0.2%Sc (7pH for pH value, 9 l/min for flow rate and 10% of sand)

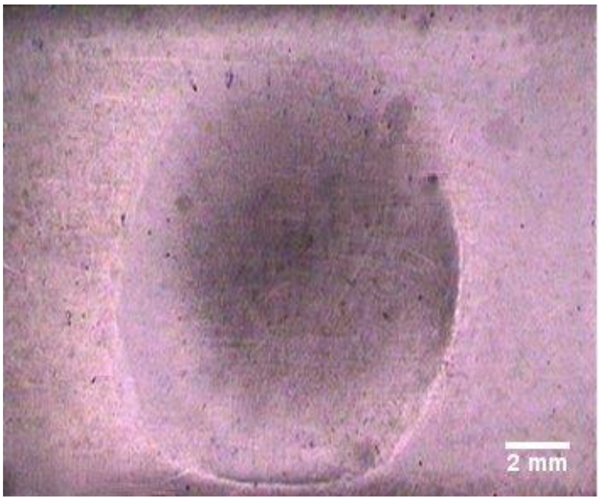

Fig 5b: High erosion corrosion behaviour of AA7075 – 0.2%Sc (10pH for pH value, 15 l/min for flow rate and 15% of sand)