Wear behavior of Al-Si (LM 6) ALLOY: an experimental study

R Manjunatha
Asst.Professor, SDMIT, Ujire – 574 240
India

Chandrashekariah
Professor, KIT, Tiptur-577252
India

Girish Kumar
Professor, SDMIT, Ujire – 574 240
India

Abstract- In the recent years the usage of cast Al-Si alloys components in automotive and marine industries has increased significantly. Such alloys are invariably treated for modification prior to casting to achieve improved properties and performance. Modification results in fine fibrous eutectic silicon which otherwise exists in the form of large plate or needle like morphology. Grain refinement places a crucial role in improving characteristics and properties of aluminum silicon (Al-Si) alloys. In this present investigation modified and grain refined Al-Si alloys are synthesized from commercially available LM 6, alloy using die casting methods. For these materials wear test is carried out. From experimental results, It is observed that as the modifier concentration increased, wear loss of LM 6 decreased almost linearly at all the sliding speeds.

Keywords – Al-Si alloys, Grain refiner and modifier,

I. INTRODUCTION

The unique combination of properties provided by Aluminum and its alloys make aluminum one of the most economical and attractive materials for a broad range of applications. Hence, the applications of these alloys industries and machine parts are increasing day to day in the industry [1- 3]. Amongst the commercial aluminum casting alloys Al–Si alloys are the most common, particularly due to some very attractive characteristics such as high strength to weight ratio, excellent castability, pressure tightness, good thermal conductivity, good mechanical properties, high fluidity, superior corrosion resistance, good weldeability, reduction in shrinkage and low coefficient of thermal expansion during solidification. Al–Si alloys find wide range of applications in marine castings, motor cars and lorry fittings, pistons and engine parts, cylinder blocks and heads, cylinder liners, axles and wheels, rocker arms, automotive transmission casings, water cooled manifolds and jackets, piston for internal combustion engines, pump parts, high speed rotating parts and impellers, etc. [1, 3-7]. Aluminum alloys have been used effectively for above applications to increase energy-saving and to reduce exhaust-emissions by means of the weight reduction. Impact absorption parts and suspension parts have been replaced by aluminum alloy castings for further weight reduction. To perform the replacement, it is important to develop the aluminum alloy castings possessing a high quality and a high reliability [8, 9]. There are basically three classes of Al-Si foundry alloys, namely, hypoeutectic, eutectic and hypereutectic. Hypoeutectic alloys are used for general applications mostly in as-cast condition. Alloys with silicon <3% are used in heat-treated condition for marine fittings while alloys with 3-5% silicon are used in rotors, vessels, valve bodies, fan blade fittings etc. Eutectic alloys (11-13% silicon) are used for pistons, cylinders, blocks and heads of IC engines in automobile and aeronautical industries. Hypereutectic alloys (>13% silicon) possess outstanding wear resistance, low thermal expansion coefficient in addition to good castability. These are used in diesel engine pistons [4].The in-service performance of the Al–Si alloy castings primarily depends on their microstructures. The correlation of mechanical properties with microstructure parameters can be very useful for planning solidification conditions in order to achieve a desired level of final properties [10, 11]

II. WEAR TEST EXPERIMENTS

Wear behavior of different samples was studied by conducting several wear tests on pin on-disc wear test machine (DUCOM Wear and Friction Monitor, TR-20E-PHM400). Wear test specimens of 10 mm ϕ×35 mm length were machined from castings. The machine is designed to apply loads up to 200 N, speed up to 2000 rpm, track diameter up to 100 mm. The wear measurement range is 0 to 2000 micron. The specimens were slid against hardened (60HRC) and ground (1.6 Ra Surface Roughness) EN-31 steel discs (containing 0.9% C, 0.35% Si, 0.75% Mn, 0.05%S, 1.6% Cr and 0.05%P). The disc is of 165 mm diameter and 8 mm thickness. Wear was measured in weight loss method using 0.0001 g balance and the frictional force was measured using load cell. The wear test specimens were cleaned using acetone after each test. The wear tests were carried out under varying normal load, different sliding speeds, at room temperature.

Table 1: The experimental parameter used in wear test

1	Alloys tested	A1	Al-12Si			
		A2	Al-12Si+0.03%Sr			
		A3	Al-12Si+0.04%Sr			
		A4	Al-12Si+0.05%Sr			
2	Load in N		9.81	19.62	29.43	39.24
	Pressure N/mm2 (d=10mm)		0.1249	0.2498	0.3747	0.4996
3	Speed in rpm		200	400	600	
	Sliding speed in m/s		1.0472	2.0944	3.1416	

Figure1: DUCOM wear and friction monitor pin on disc wear testing machine

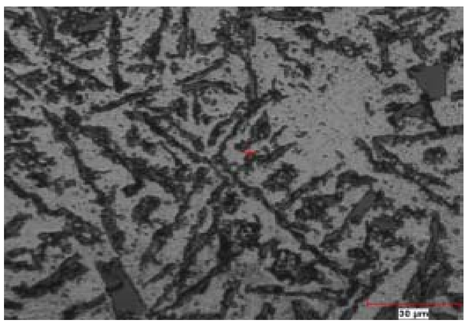
Following wear parameters were evaluated during the test.

1. Weight loss in grams.
2. Volume loss in mm3.
3. Height loss in microns.
4. Linear wear rate = $\frac{\text{Thickness of the layer removed}}{\text{Sliding distance}}$ mm/m
5. Wear rate = $\frac{\text{Weight loss}}{\text{Sliding distance}}$ g/m
6. Volumetric wear rate = $\frac{\text{Volume of the material removed}}{\text{Sliding distance}}$ mm3/m
7. Specific wear rate = $\frac{\text{Volume of the material removed}}{\text{Normal Load (N)} \times \text{Sliding distance}}$ mm3/N-m
8. Wear resistance = $\frac{\text{Normal Load (N)} \times \text{sliding distance}}{\text{Volume of the material removed}}$ N-m/mm3

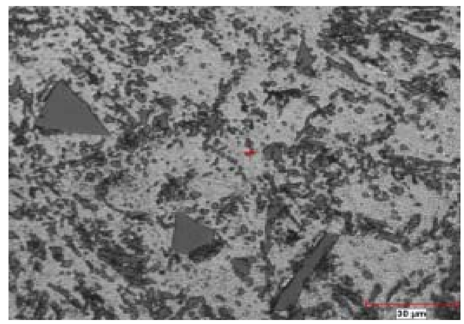
III. Results and discussion

The results of wear experiments are presented in Tables 2-4. Table 2 contains the results of wear test of LM6 alloy recorded and determined at the end of 10 minutes when the disc was rotated at 200 rpm. Similar results for the alloy at 400 rpm and 600 rpm disc speeds are provided in Tables 3 and 4 respectively.

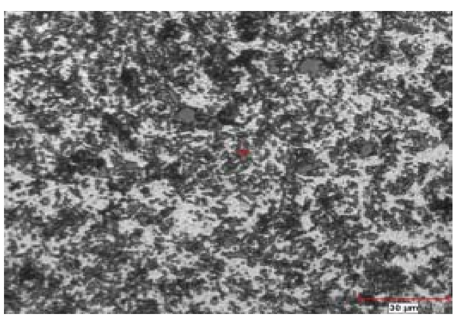
As expected, the wear loss increased with increase in time, sliding distance and normal load (normal pressure). However, the extent of increase was different for different alloy conditions. That means, modified alloys showed lower wear rates compared to unmodified alloys. Among the modified alloys, the wear rate showed variation with the concentration of modifier present. Hence, as a general remark, it can be stated that the modification has a significant effect on the wear behavior of LM 6 alloys. The possible reason for this would be refinement of microstructure from acicular Si morphology (which is generally brittle) to fibrous morphology as shown in the photomicrographs given below. It can also be noted that, as the modifier concentration was increased the refinement was also more.



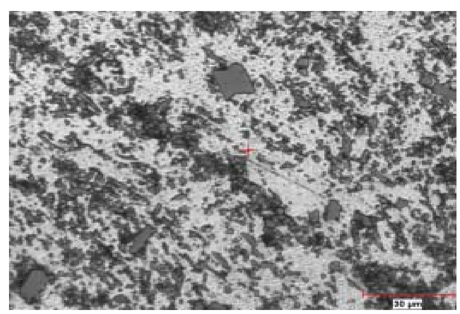
0 wt. % Sr (Unmodified)



0.03 wt. % Sr (Modified)



0.04 wt. % Sr (Modified)



0.05 wt. % Sr (Modified)

Figure 2: Microstructures of unmodified and modified LM 6 alloys

Table 2: Wear test data, with constant speed (200 rpm), Track diameter (140 mm), Time (10 min), Sliding speed 1.570 m/s, Pin diameter 10mm, at room temperature.

Load (Kg)	Alloy No.	Weight loss (g)	Volume loss mm3	Height loss microns	Specific wear rate ×10-3 mm3/N-m	Wear resistance ×10-3 Nm/mm3	Friction force (N)
1kg	A1	0.0021	0.7919	10.0822	0.0856	11.6760	2.0502
	A2	0.0019	0.7164	9.1220	0.0775	12.9051	2.7075
	A3	0.0039	1.4706	18.7241	0.1591	6.2871	2.4672

	A4	0.0037	1.3952	17.7639	0.1509	6.6269	2.3396
2kg	A1	0.0094	3.5445	45.1299	0.1917	5.2169	5.6505
	A2	0.0083	3.1297	39.8488	0.1693	5.9083	5.6211
	A3	0.0076	2.8658	36.4880	0.1550	6.4525	5.7290
	A4	0.0088	3.3183	42.2493	0.1794	5.5726	5.5328
3kg	A1	0.0109	4.1101	52.3315	0.1482	6.7485	8.7554
	A2	0.0089	3.3560	42.7294	0.1210	8.2650	8.7229
	A3	0.0081	3.0543	38.8885	0.1101	9.0813	8.3581
	A4	0.0102	3.8462	48.9708	0.1387	7.2117	8.7259
4kg	A1	0.0142	5.3544	68.1750	0.1448	6.9069	11.0853
	A2	0.0129	4.8643	61.9336	0.1315	7.6030	11.5169
	A3	0.0117	4.4118	56.1723	0.1193	8.3828	10.8690
	A4	0.0121	4.5437	57.8527	0.1229	8.1393	11.2815

Table 3: Wear test data, with constant speed (400 rpm), Track diameter (140 mm), Time (10 min), Sliding speed 3.142 m/s, Pin diameter 10mm, at room temperature

Load (Kg)	Alloy No.	Weight loss (g)	Volume loss mm3	Height loss microns	Specific wear rate×10-3 mm3/N-m	Wear resistance×10-3 N-m/mm3	Friction force (N)
1kg	A1	0.0120	4.5249	57.6127	0.2447	4.0866	2.2219
	A2	0.0106	3.9970	50.8912	0.2162	4.6263	1.7412
	A3	0.0106	3.9970	50.8912	0.2162	4.6263	1.8050
	A4	0.0092	3.4691	44.1697	0.1876	5.3304	1.8835
2kg	A1	0.0249	9.3891	119.5463	0.2539	3.9389	4.7578
	A2	0.0186	7.0136	89.2996	0.1896	5.2730	5.2679
	A3	0.0134	5.0528	64.3341	0.1366	7.3193	4.8461
	A4	0.0167	6.2971	80.1776	0.1703	5.8730	4.6303
3kg	A1	0.0352	13.2730	168.9971	0.2393	4.1795	7.7842
	A2	0.0323	12.1795	155.0741	0.2196	4.5547	8.2992
	A3	0.0305	11.5008	146.4322	0.2073	4.8235	8.7113
	A4	0.0343	12.9336	164.6762	0.2331	4.2891	8.3434
4kg	A1	0.0395	14.8944	189.6417	0.2014	4.9660	10.6536
	A2	0.0367	13.8386	176.1987	0.1871	5.3449	11.7523
	A3	0.0331	12.4811	158.9149	0.1687	5.9262	11.6346
	A4	0.0408	15.3846	195.8830	0.2080	4.8078	10.8498

Table 4: Wear test data, with constant speed (600 rpm), Track diameter (140 mm), Time (10 min), Sliding speed 4.712 m/s, Pin diameter 10mm, at room temperature.

Load (Kg)	Alloy No.	Weight loss (g)	Volume loss mm3	Height loss microns	Specific wear rate ×10-3 mm3/N-m	Wear resistance×10-3 N-m/mm3	Friction force (N)
1kg	A1	0.0100	3.7707	48.0106	0.1359	7.3559	1.9570
	A2	0.0096	3.6199	46.0901	0.1305	7.6624	2.3691
	A3	0.0064	2.4133	30.7268	0.0870	11.4936	2.3544
	A4	0.0062	2.3379	29.7665	0.0843	11.8643	2.5604
2kg	A1	0.0121	4.5626	58.0928	0.0822	12.1585	4.6107
	A2	0.0142	5.3544	68.1750	0.0965	10.3604	4.5322
	A3	0.0121	4.5626	58.0928	0.0822	12.1585	5.1012
	A4	0.0117	4.4118	56.1723	0.0795	12.5742	5.3464

3kg	A1	0.0162	6.1086	77.7771	0.0734	13.6220	8.6377
	A2	0.0170	6.4103	81.6179	0.0770	12.9810	8.2109
	A3	0.0170	6.4103	81.6179	0.0770	12.9810	8.6524
	A4	0.0191	7.2021	91.7002	0.0866	11.5537	9.0055
4kg	A1	0.0215	8.1071	103.2227	0.0731	13.6854	11.4384
	A2	0.0172	6.4857	82.5781	0.0585	17.1067	11.4384
	A3	0.0217	8.1825	104.1829	0.0738	13.5592	11.8701
	A4	0.0178	6.7119	85.4588	0.0605	16.5301	10.5359

A. Effect of Modification on Weight Loss:

Figure 3 shows the effect of modifier present in the LM6 alloy on wear loss (weight loss during wear test in grams) at 200 rpm. Figures 4 is corresponding plots at 400 rpm respectively.

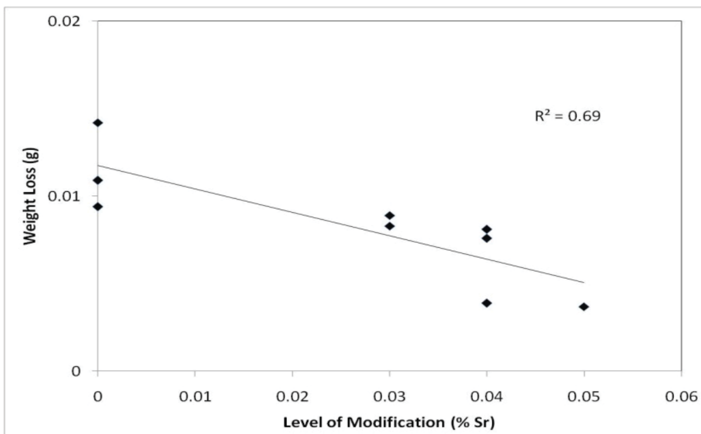


Figure 3: Effect of Modification on weight loss at 200 rpm

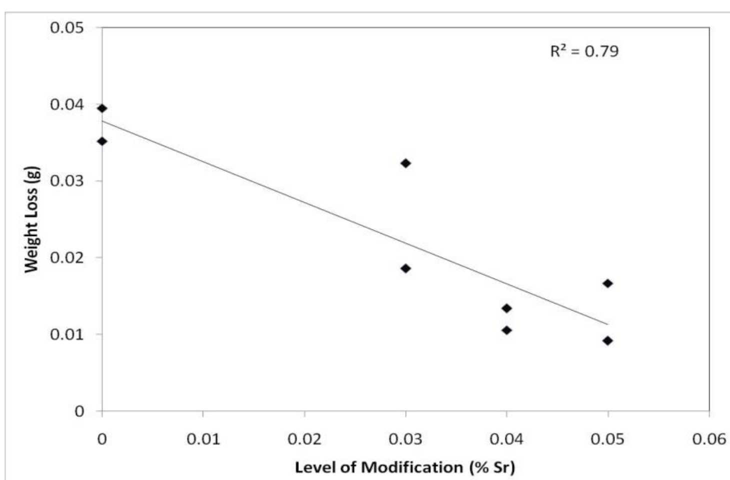


Figure 4: Effect of Modification on weight loss at 400 rpm

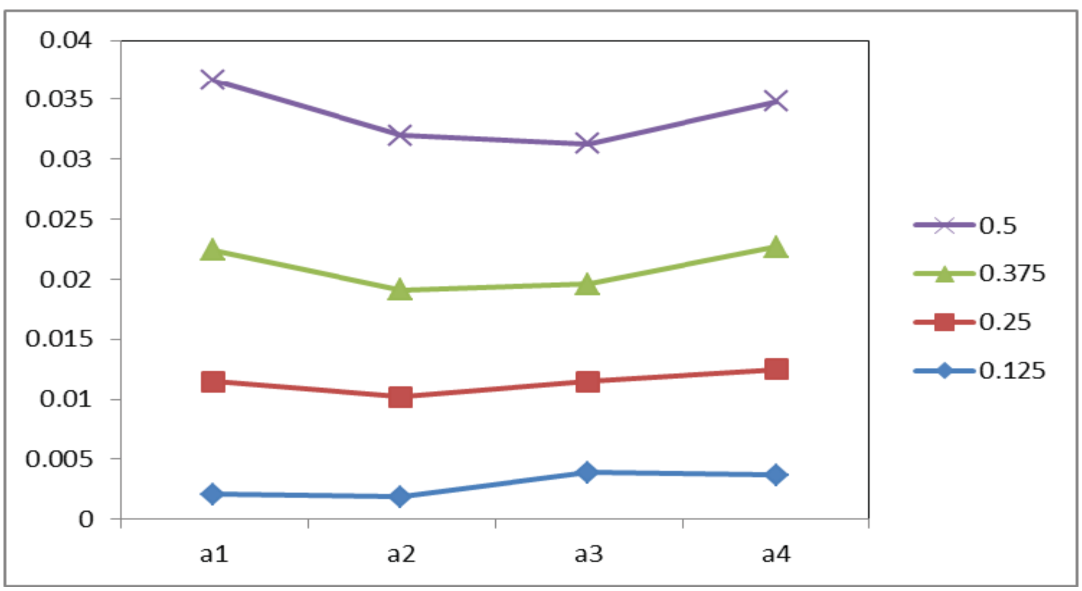
It is clear from the graphs that, the level of modification has resulted in decrease in wear loss. For example, at 600 rpm, at 1 kg load, the wear loss found in unmodified LM6 alloy (A1) is 0.01 g. The corresponding values in the modified alloy are lower (0.0096 g at 0.03 wt. % Sr addition, 0.0064 g at 0.04 wt.% Sr addition and 0.0062 g at 0.05 wt.% Sr addition). Almost similar behavior is exhibited by the alloys at the investigated speeds as seen from the figures although there are some variations at higher modifier concentrations. Hence, it can be stated that, the modification of the alloy makes it better wear resistance

B. *Effect of Normal Pressure on Wear Loss:*

Table 5 presents the data related to loss of weight (g) during wear test of different LM6 alloys (unmodified and modified) at normal pressures of 0.125 N/mm2, 0.25 N/mm2, 0.375 N/mm2 and 0.5 N/mm2 (corresponding to the loads 1 kg, 2 kg, 3 kg and 4 kg) at 200 rpm. As expected, increase in the normal load has resulted in the increase in the wear loss. This is in agreement with the results found in literature [25]. However, the addition of modifier has affected the extent of variation. Similar results are observed at higher speeds as well.

Table 5: Effect of normal pressure on weight loss of LM6 alloys at 200 rpm

	Weight loss (g) for different alloys			
Normal Pressure (N/mm2)	A1	A2	A3	A4
0.125	0.0021	0.0019	0.0039	0.0037
0.250	0.0094	0.0083	0.0076	0.0088
0.375	0.0109	0.0089	0.0081	0.0102
0.500	0.0142	0.0129	0.0117	0.0121

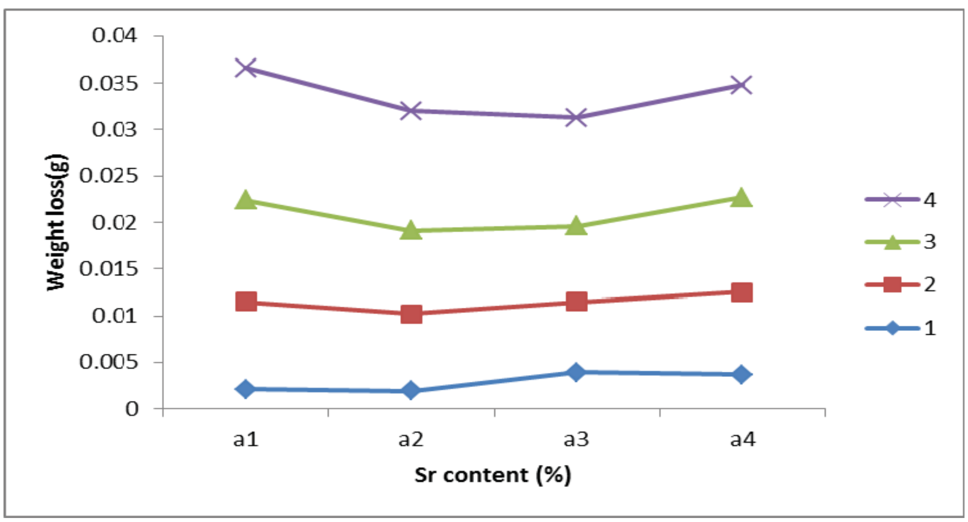


Graphical representation for the variation of graph Normal Pressure (N/mm2) V/S Weight loss (g)

Table 6 shows the increase in wear loss of the alloys when the normal load is changed from 1 kg to 2kg, 2kg to 3 kg and 3 kg to 4 kg. As the strontium addition is increased the increase in loss is reduced. For example, for the increase in normal load from 1 kg to 2 kg, the increase in wear loss for unmodified alloy is 0.0073 g whereas the corresponding values for modified alloys with Sr content 0.03 wt.%, 0.04 wt. % and 0.05 wt.% are 0.0064 g, 0.0037 g and 0.0051 g respectively. Similar trend is also observed when the normal load is increased from 2 to 3 kg and 3 to 4 kg. These results clearly indicate that, the addition of modifier is effective in controlling the wear. It may also be noted that, there could be some optimum modifier quantity which results in best wear behaviour. If the modifier quantity is further increased (beyond optimum), the loss of wear would also increase. In the investigated experiments, the Sr has shown its effect almost up to 0.04 wt.%.

Table 6: Effect of modification level on wear

	Increase in weight loss (g) for the change in normal load from		
Sr content (%)	1kg to 2kg	2kg to 3kg	3kg to 4kg
0	0.0073	0.0015	0.0033
0.03	0.0064	0.0006	0.004
0.04	0.0037	0.0005	0.0036
0.05	0.0051	0.0014	0.0019



Graphical representation for the variation of graph Sr content (%) V/S Weight loss (g)

IV. CONCLUSION

- Modification treatment of LM 6 alloy with Sr modifier has resulted in significant refinement and modification of microstructure. The unmodified alloy microstructure consisted of flaky acicular
- silicon morphology which has hanged to fibrous morphology on treatment with Sr modifier. The extent of refinement was higher with higher modifier concentrations.
- Wear loss increased with increasing time, sliding distance and normal pressure for all LM 6 alloys (unmodified and modified with different concentrations of Sr modifier). The extent of variation of wear loss was different for modified and unmodified alloys with modified alloy showing better wear resistance.

- As the modifier concentration increased, wear loss of LM 6 decreased almost linearly at all the sliding speeds investigated.

REFERENCES

[1] "A Review on effect of grain refinement and modification on the dry sliding wear behaviour of eutectic Al– Si alloys", Akul Patel, Ashwin Bhabhor and Vipul Patel, International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 3, May-June 2012, pp. 417-2421.

[2] "Introdcuction to Aluminium and its alloys", E.S. Dwarakadasa in National Workshop on Science and Engineering Practice of Aluminum casting practice held on 22-24 September 2006 at NITK Surathkal.

[3] "Mechanical Properties of the Modified Al-12%Si Alloy Reinforced by Ceramic Particles", Haitham Razouqi Saleh, Eng. & Tech. Journal, Vol.28, No. 2 , 2010, pp. 289-300.

[4] "Mechanism & Non-destructive Assesment of Modification Melt Treatment of Al-Si Alloys - a review", Girish Kumar, Hegde S and Prabhu K.N., Indian Foundry Journal, vol. 51, 2005, pp. 25-40.

[5] "Effect of Modifier and Grain Refiner on Cast Al-7si Aluminum Alloy: A Review", N. R. Rathoda and J.V. Manghani, International Journal of Emerging Trends in Engineering and Development, Issue 2, Vol.5.(July-2012), pp. 573-581.

[6] "Reviews on the influences of alloying elements on the microstructure and mechanical properties of aluminum alloys and aluminum alloy composites", R. S. Rana, Rajesh Purohit, and S. Das, International Journal of Scientific and Research Publications, Volume 2, Issue 6, June 2012, pp. 1-6.

[7] "Improvement of mechanical properties of AlSi7Mg alloy with fast cooling homogenous modifier", T. Lipiñski, Archives of Foundry Engineering Volume 8, Issue 1 / 2008, pp. 85 – 88.

[8] "Influence of Purity on Tensile Property of Al–Si Hypo-Eutectic Alloy Castings", Toshifumi Ogawa, Shigeyuki Haruyama, Hidenori Era and Katsuhiko Kishitake, Materials Transactions, Vol. 46, No. 8 (2005) pp. 1771 – 1774.

[9] "The Mechanical Properties Optimizing of Al - Si Alloys Precipitation Hardening and the Effect on the Character of the Chip", Š. Michna and N. Naprstková, Acta Metallurgica Slovaca, Vol. 17, 2011, No. 3, pp. 193-199.

[10] "Corrosion Resistance and Mechanical Properties of an Al 9wt%Si Alloy Treated by Laser Surface Remelting", Wislei R. Osório, Noé Cheung, Leandro C. Peixoto and Amauri Garcia, Int. J. Electrochem. Sci., 4 (2009) pp. 820 – 831.

[11] "Mechanical Properties of Al-Si-Mg Alloy Castings as a Function of Structure Refinement and Porosity Fraction", M. Hajkowski, Bernat and J. Hajkowski, Archives of Foundry Engineering Volume 12, Issue 4 / 2012, 57 – 64.

[12] "Influence of Melt Treatments on Dry Sliding Wear Behavior of Hypereutectic Al-15Si-4Cu Cast Alloys", P.V. Chandra Sekhar Rao, A. Satya Devi and K.G. Basava Kumar, Jordan Journal of Mechanical and Industrial Engineering, Volume 6, Number 1, Feb. 2012, pp 55 – 61.

[13] "Effects of strontium and boron interactions in Al-7Si alloys", Research and Development – China Foundry, Vol. 7, No. 4, November 2010, pp. 325-330

[14] "Effects of Strontium on the Microstructure of Al-Si Casting Alloys", Anett Kósa, Zoltán Gácsi and Jenő Dúl, Materials Science and Engineering, Volume 37/2. (2012), pp. 43–50.

[15] "Effect of the grain refinement, modification and the cooling rate on microstructure of the AlSi10Mg alloy", Mitja Petrič, Jožef Med ved and Primož Mrvar, Materials and Geo environment, Vol. 53, No. 3, pp. 385-401, 2006.

[16] "Effects and mechanisms of grain refinement in aluminium alloys", K. T. Kashyap and T. Chandrashekar, Bull. Mater. Sci., Vol. 24, No. 4, August 2001, pp. 345–353.

[17] "Microstructural and wear behavior of hypoeutectic Al–Si alloy (LM25) grain refined and modified with Al–Ti–C–Sr master alloy", A.K. Prasada Rao, K. Das, B.S. Murty and M. Chakraborty, Wear 261 (2006) pp. 133–139.

[18] "Eutectic Modification of Al-Si Alloys with Rare Earth Metals", Kazuhiro Nogita, Stuart D. McDonald and Arne K. Dahle, Materials Transactions, Vol. 45, No. 2 (2004) pp. 323-326.

[19] "Influence of Grain Refiner and Modifier on the Microstructure and Mechanical Properties of A356 Alloy", D. G. Mallapur, K. Rajendra Udupa and S. A. Kori, International Journal of Engineering Science and Technology, Vol. 2(9), 2010, 4487-4493.

[20] "Microstructural and mechanical properties of eutectic Al–Si alloy with grain refined and modified using gravity-die and sand casting", V.P.Patel and H.R PRAJAPATI, International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 3, May-Jun 2012, pp.147-150.

[21] "Effect of Si Content on Turning Machinability of Al-Si Binary Alloy Castings", Masatsugu Kamiya, Takao Yakou, Tomohiro Sasaki and Yoshiki Nagatsuma, Materials Transactions, Vol. 49, No. 3 (2008) pp. 587 to 592.

[22] "An Overview of the Development of Al-Si-Alloy Based Material for Engine Applications", Haizhi Ye, Journal of Materials Engineering and Performance, Volume 12(3) June 2003, pp. 288-297.

[23] "Dry Sliding Wear Behaviour of Hypereutectic Al-15Si and Al-15Si-4Cu Cast Alloys by Melt Treatments", P. V. Chandra Sekhar Rao, A. Satya Devi and K. G. Basava Kumar, Indian Foundry Journal, Vol. 57, No. 12, December 2011, pp 23-28.

[24] "Tribological Properties of Al-Si Alloy A356 Reinforced With Al2O3 Particles", A. Vencl, A. Rac, I. Bobić and Z. Mišković, Tribology in industry, Volume 28, No. 1 & 2, 2006, pp. 27-31.

[25] "Effect of grain refinement and modification on the dry sliding wear behavior of eutectic Al–Si alloys", T.M. Chandrashekharaiah and S.A. Kori, Tribology International 42 (2009) 59–65.