International Journal of
Science and Engineering Investigations vol. 7, issue 83, December 2018
ISSN: 2251-8843

Investigation of the Effects of Casting Method on Cooling Plate on Tribological Properties of A357 Aluminum Alloy with Taguchi Method

Murat Çolak[1], Salih Hakan Yetgin[2]
[1]Bayburt University, Faculty of Engineering, Mechanical Engineering Department, Bayburt, Turkey
[2]Kütahya Dumlupinar University, Simav Technology Faculty, Mechanical Engineering Department, Kütahya, Turkey
([1]mcolak@bayburt.edu.tr, [2]shyetgin@gmail.com)

Abstract- It is known that by providing a non-dendritic and fine-grained structure in the casting of aluminum alloys, occur the better sustentation and nonporous structure, improve the mechanical properties, fatigue resistance and sealing resistance values. Due to this reason, several methods have been studied on the modification of the microstructure of aluminum alloys and the improvement of their properties. Some of these methods, incorporation of grain refiners (Ti and B based) master alloy into the casting, the casting under mechanical vibration, electromagnetically stirring during casting solidification and the casting in inclined cooling plate. The method of the casting in the inclined cooling plate provides more advantageous than the other methods in terms of installation and application cost. Casting quality of the inclined cooling plate casting is influenced by parameters such as slope angle of plate, casting length on the plate, amount of cooling water flow rate and casting temperature. In this study, the effect of the inclined cooling plate casting factors on the microstructure and wear properties of A357 aluminum alloy which has Al-Si-based broad solidification range and high fluidity, was investigated through the Taguchi experimental design method. The abrasion tests were carried out by utilizing a pin-disc system via dry environmental conditions of 1040 steel disc. Moreover, the determination of chemical composition with spectrometry, micro structure investigation, wear tests ,determination of friction coefficient and wear rates of casting has been done during the this study. Consequently, ıt was established the optimum casting conditions for the production of materials with fine grains and good wear characteristics in the casting of the A357 aluminum alloy by the inclined cooling plate method.

Keywords- *A357, Inclined Cooling Plate Casting, Wear, Taguchi Statistical Method*

I. INTRODUCTION

In the automotive industry, to reduce fuel consumption and reduce negative impacts on the environment, it is needed to use light alloys such as aluminum. What is more, it is known that the aluminum is utilized for the production of many parts in the automotive industry. Microstructure, mechanical and wear properties of aluminum alloys are need to be improved by direction of demands of automotive manufacturers [1-2]. The structure that is emerged during solidification in aluminum based casting alloys; effects the mechanical properties and it is needed the further processing to obtain the desired properties. In particular, grain size and shape can be controlled by solidification. It is known that by providing a non-dendritic and fine-grained structure in the casting of aluminum alloys, occur the better sustentation and pore-free structure, improve the mechanical properties, fatigue resistance and sealing resistance values. Due to this reason, several methods have been studied on the modification of the microstructure of aluminum alloys and the improvement of their properties. Some of these methods, incorporation of grain refiners (Ti and B based) master alloy into the casting, the casting under mechanical vibration, electromagnetically stirring during casting solidification and the casting in inclined cooling plate[3-12]. .

In casting method in inclined cooling plate; the molten alloy is poured over a water-cooled sloped surface. This method was first developed by Haga [13]. The method of the casting in the inclined cooling plate can be installed with very little equipment and low operating costs [14-16]. In this process, the molten metal at the proper temperature is poured into the mold along the inclined plate made of plain carbon steel. Solid cores are formed due to the rapid heat transfer between the molten and the inclined plates. These cores are separated from the surface as a result of applied shear stress and metal flow. As a result, solidification starts on the surface of the cooled plate then the nucleated particles grow and separated from the plate surface by liquid movement and finally it filled the mold. In this method, the temperature of the liquid alloy poured over the cooled surface should be low, as it starts to solidify as it flows from the surface [17].

A lots of studies have been carried out to improve the mechanical and tribological properties of Al alloys via heat treatment, addition of alloying element and grain refiners, and using different casting method. Ardakan [18] was investigated tribological properties of A390 (Al–17Si–4.5Cu–0.5Mg) hypereutectic Al–Si alloy and, 6 and 10 wt% Mg filled alloys. Zeren et al. [19] were examined the effect of Cu content on the microstructure and hardness of near-eutectic Al-Si-(25%)Cu. Savaskan and Alemdag [20] were fabricated Al–40Zn–3Cu and Al–40Zn–3Cu–(0.5–3)Ni alloys by permanent casting. In their studies were investigated microstructural and mechanical properties, and wear and friction behavior were analyzes with block-on-disc device. Very little research has investigated the mechanical and wear behaviour of Al alloy by using cooling-slope-cast. Thuong et al. [21] investigated the effect of use of a cooling slope on the microstructure, hardness and wear behavior of Al7Si-Mg alloy. The Al-7Si-Mg alloy was cast with and without a cooling slope at a pouring temperature of 6408C. The result showed that the wear mechanism was found to be a combination of adhesion, delamination, oxidation and abrasive wear for both cooling slope- and conventionally cast samples. The cooling slope cast samples with fine and globular α-Al phase, high hardness and low specific wear rate showed. Deepak Kumar et all [22] examined that the effect of pouring temperature, slope angle and cooling length on the hardness of A356 alloy produced by using cooling slope casting technique. Khosravi and Akhlaghi [23] investigated that the influences of SiC content on the microstructure, porosity, hardness and wear resistance of A356−SiCp composites processed via two different methods of compocasting and vibrating cooling slope (VCS). Saghafian et all. [24] investigate the effect of semisolid processing on the wear behavior of Al-25 wt% Mg2Si composite. The tribological tests were carried out with pin-on-disc method at three different applied loads and dry sliding conditions.

In this study, it was aimed to determine the optimum casting conditions for the production of non-dendritic materials with good ductility and high strength and abrasion resistance properties by inclined cooling plate casting method. A357 aluminum alloy which has Al-Si-based broad solidification range and high fluidity, was utilized. A357 alloy; is generally a ductile material having higher elongation values, good workability and higher tensile strength. It is used extensively in structural parts requiring high stress values, in aircraft industry and automotive sector [17]. In this study, castings were done in order to examine whether the plate inclination angle, casting length and casting temperature parameters affecting the casting quality on inclined casting cooling plate.

II. EXPERIMENTAL DETAILS

In this study, it is aimed to investigate experimentally the possible factors that affect the wear characteristics of A357 aluminum alloy cast on inclined casting cooling plate. For this purpose, the casting was carried out under different conditions by changing inclined plate angle, casting length and casting temperature and the effects of these parameters on the microstructure and mechanical properties of the casting material were investigated. The effects of breaking the dendrite arms during solidification were also examined. Thus, it is aimed to produce materials with good abrasion resistance. Experimental parameters and levels are given in Table 1. Taguchi experimentel design method is known to be used for optimizing parameters to eliminate any variations that need to be investigated [25]. In this study, Taguchi experimental design approach was used based on the 4 factors which are summarized in Table 1. The mixed L16 orthogonal array has been selected. First column is assigned to Casting Length on Plate; second column to Plate Angle, third column is Casting Temperature; and the last column is set to Flow. In the scope of the study, the melting of A357 aluminum casting alloy was carried out in a silicon carbide based crucible by using electric resistance furnace. The chemical analysis of the alloys used in the experiments are given in Table 2.

TABLE I. EXPERİMENTAL PARAMETERS AND LEVELS

Experimental Parameters	Levels			
	1	2	3	4
Casting Length on Plate	200 mm	350 mm	500 mm	600 mm
Sloped Plate Angle	30 °	45 °	60 °	75 °
Casting Temperature	620 °C	650 °C	-	-
Flow	On	Off		

TABLE II. CHEMİCAL ANALYSİS OF A357 ALLOY (% WT.)

Alloy	Al	Fe	Si	Cu	Mn	Mg	Zn	Ti
Element, %	Balance	0,16	7,21	0,02	0,01	0,48	0,04	0,11

The liquid alloy was subjected to washing process of liquid nitrogen with the help of graphite lance at 700 ° C and the slag on the liquid metal surface was cleaned. It should be stated here that this process is done in order to remove the hydrogen in the liquid metal before casting. Die casting was performed after the temperature of liquid metal reaches the appropriate temperature correspond with the experimental parameters. The angle of the inclined cooling plate and the water passing through it were determined according to the parameters and poured with the aid of a bucket. Fig. 1 indicates a solid model image of the inclined casting cooling plate used in the experiments and a graphite mold image of the castings. Casting sample was removed from the mold after solidification in the graphite mold and cooling down was achieved. Samples were taken from casting samples to make wear tests and microstructure studies. Subsequently, the samples were metallographically prepared, microstructure studies were carried out using the Clemex Vision Lite image analysis program on images taken with a Nikon Eclipse L150A optical microscope and its associated camera.

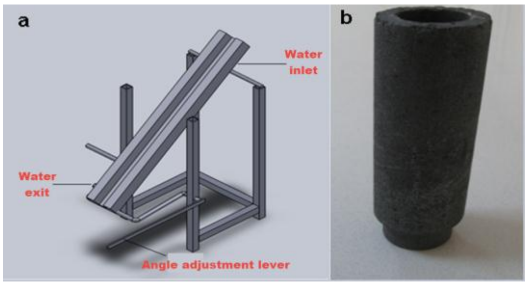

Figure 1. a) Schematic view of the cooling slope plate test setup, b) Graphite mold.

Wear tests were carried out on a pin-on-disc wear test configuration at room temperature under dry conditions. The cylindrical pin flat ended specimens of size 6 mm in diameter and 50 mm length were tested against steel disc. Fig. 2 represents a schematic diagram of the pin-on-disc wear test configuration that was designed and used for this work. Sliding wear data reported here is the average of at least three runs. The average mass loss was used to calculate the specific wear rate (K_o) as

$$K_o = \Delta m / L . F . \rho \qquad (m^2/N) \qquad (1)$$

Δ_m is average mass loss (g), L is sliding distance (m), F is the applied load (N) and ρ is density of the materials (g cm^{-3}).

Figure 2. Schematic diagram of wear test machine

III. Results and Discussion

A. Analysis of Control Factors

TABLE III. Experimental design for coefficient of friction using mixed L16 orthogonal array

	Casting Length on Plate (mm) (A)	Plate Angle (°) (B)	Casting Temperature (°C) (C)	Flow (D)	Coefficient of Friction	S/N Ratio
1	200	30	620	Yes	0,2542	11,8964891
2	200	45	620	Yes	0,2496	12,0551084
3	200	60	650	No	0,2388	12,4393136
4	200	75	650	No	0,2392	12,4247765
5	350	30	620	No	0,2322	12,6827557
6	350	45	620	No	0,2258	12,9255212
7	350	60	650	Yes	0,218	13,2308701
8	350	75	650	Yes	0,2192	13,183189
9	500	30	650	Yes	0,2126	13,4487348
10	500	45	650	Yes	0,2082	13,6303855
11	500	60	620	No	0,206	13,7226556
12	500	75	620	No	0,2086	13,6137139
13	600	30	650	No	0,1972	14,1018618
14	600	45	650	No	0,1946	14,2171433
15	600	60	620	Yes	0,197	14,1106755
16	600	75	620	Yes	0,1982	14,057927

Minitab 15.0 software was used to analyze each control factor (Casting Length on Plate, Sloped Plate Angle, Casting Temperature, Flow) on the coefficient of friction of A357 alloy. Signal to Noise (S/N) ratios are given in Table 3. S/N response and related mean response is given in Table 4 and 5 respectively. The strongest influence according to the control factor was determined by checking the highest difference. It was found that Casting Length on Plate is the dominant factor.

TABLE IV. Response Table for Signal to Noise Ratios

Level	Casting Length on Plate (mm)	Plate Angle (°)	Casting Temperature (°C)	Flow
1	12,2	13,03	13,13	13,2
2	13,01	13,21	13,33	13,27
3	13,6	13,38		
4	14,12	13,32		
Delta	1,92	0,34	0,2	0,06
Rank	1	2	3	4

TABLE V. Response Table for Means

Level	Casting Length on Plate (mm)	Plate Angle (°)	Casting Temperature (°C)	Flow
1	0,2455	0,224	0,2214	0,2196
2	0,2238	0,2196	0,216	0,2178
3	0,2089	0,2149		
4	0,1968	0,2163		
Delta	0,0487	0,0091	0,0055	0,0018
Rank	1	2	3	4

Fig. 3, shows the main effects of S/N ratios for the coefficient of friction. From these plots, according to the shift in levels, optimum test condition can be determined. As seen in Figure 4,it is evident that casting length on plate has the most significant effect. And also A4B3C2D2 conditions are found to be the optimal conditions for coefficient of friction.

B. Analysis of Variance

Percentage of contribution (P%) from ANOVA analysis gives the degree of influence of the parameter. An 'F-Test' values of lower than '5%' is considered to be statistically insignificant. Table 6, shows that the ANOVA for coefficient of friction. The percentage contribution of A, B, C, and D are 94,02 percent,3,501 percent, 2,134 percent and 0,236 percent respectively.

C. Confirmation Tests

In this study, four different parameters are selected to be investigated by Taguchi experimental design method (L16). Effect of Casting Length on Plate (mm), Plate Angle (°), Casting Temperature (°C), Flow on coefficient of friction is evaluated. Comparison of S/N ratio and ANOVA results has similar findings. A4B3C2D2 condition is found to be the optimal conditions for coefficient of friction.

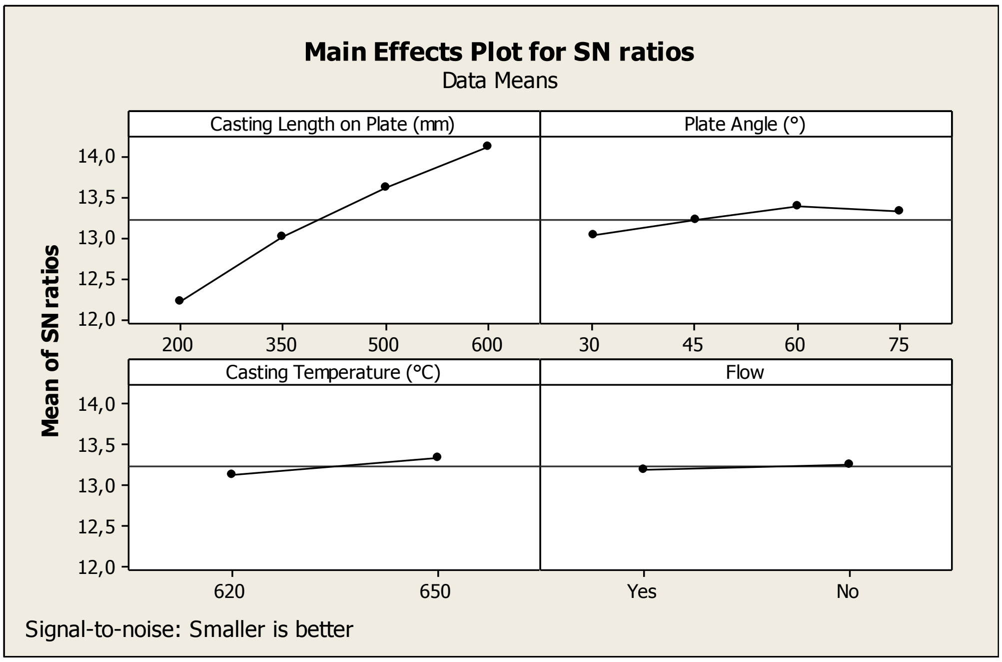

Figure 3. Effect of control factors on coefficient of friction

TABLE VI. ANALYSIS OF VARIANCE FOR COEFFICIENT OF FRICTION

Source	DF	Seq SS	Adj SS	Adj MS	F	P (%)
Casting Length on Plate (mm)	3	0,005281	0,005281	0,001760	1988,5	94,01712
Plate Angle (°)	3	0,000196	0,000196	0,000065	74,04	3,501433
Casting Temperature (°C)	1	0,000119	0,000119	0,000119	135,4	2,134325
Flow	1	0,000013	0,000013	0,000013	15,05	0,236751
Error	7	0,000006	0,000006	0,000000		
Total	15	0,005617				

TABLE VII. RESULTS OF THE CONFIRMATION EXPERIMENTS FOR COEFFICIENT OF FRICTION

	Optimal Control Parameters	
	Prediction	Experimental
Level	A4B3C2D2	A4B3C2D2
S/N ration	14,39682241	14,33452

To reduce the coefficient of friction, optimum combination of process parameters is A4 B3 C2 D2 condition, referring to the Casting Length on Plate is 600 mm, Plate Angle 60°, Casting Temperature is 650°C, and there is no Flow. The comparison of prediction and experimental results is given in Table 7. It can be seen that the difference is less than 0.05% which can be considered to be insignificant.

IV. RESULTS

In this study, the effect of the inclined cooling plate casting factors on the microstructure and wear properties of A357 aluminum alloy which has Al-Si-based broad solidification range and high fluidity, was investigated through the Taguchi experimental design method. The abrasion tests were carried out by utilizing a pin-disc system via dry environmental conditions of 1040 steel disc. For this purpose, the casting was carried out under different conditions by changing inclined plate angle, casting length and casting temperature and the effects of these parameters on the microstructure and mechanical properties of the casting material were investigated. Optimum test condition determined by Taguchi experimental design under 4 factor with mixed levels. It is evident that casting length on plate has the most significant effect. And also A4B3C2D2 conditions are found to be the optimal conditions for coefficient of friction.

REFERENCES

[1] G. K. Sighworth, T. A. Kuhn, "Refinement of Aluminium Casting Alloys, AFS Transactions", vol. 115, pp. 1-12, 2007.

[2] G. Chiarmetta, ‘‘Thixoforming of Automobile Components’’, in: Proceedings of the Fourth İnternational Conference on Semi-Solid Processing of Alloys and Composites, pp. 204-207, 1996.

[3] R. Kayıkcı, M. Çolak, "Kuma Dökülen Etial160 Alüminyum Alaşımında Tane İnceltmenin Beslenebilirlik Üzerine Etkisinin İncelenemesi," 5. Uluslararası İleri Teknolojiler Sempozyumu (IATS’09), 13-15 Mayıs 2009.

[4] Lu, H. T., Wang, L. C., Kung, S. K., Grain Refining in A356 Alloys, J. Chinese Foundrymen's Association, Vol. 29, pp. 10-18, 1981.

[5] J. Kim, J. Choi, C. Lee, E. Yoon, "A Study on The Variation of Solidification of A356 Aluminum Alloys with Sr Addition", Kluwer Academic Publishers, pp 1395-1397, 2000.

[6] S. G. Shabestari, F. Shahri, "Influence of Modification, Solidification Conditions and Heat Treatment on The Microstructure and Hechanical Properties of A356 Aluminum alloy", Kluwer Academic Publishers, pp 2023-2032, 2004.

[7] E. N. Pan, H.S. Chiou, G.J. Liao, "Effects of Modification and Solidification Conditions on the Feedeing Behaviour of A356 Al Alloy", AFS Transactions, Vol. 99, pp. 605-621, 1991.

[8] A. Figueredo, "Science and technology of semi-solid metal processing", North America Die Casting Associtation, USA, 2.1-2.17, 2001.

[9] K. Sukumaran, B.C. Pai, M. Chakraborty, "The effect of isothermal mechanical stirring on an Al–Si alloy in the semisolid condition", Materials Science and Engineering, vol. A369, pp. 275–283, 2004.

[10] M. Çolak, M. Balcı, "Study On The Effect Of The Mechanical Vibration On Solidification In Process Of A356 Aluminum Alloy Casting," International Conference on Engineering and Natural Sciences (ICENS 2016), May 24-28 Sarajevo, Bosna Herzogovina, 283-291, 2016.

[11] H. V. Atkinson, P. Kapranos, D. Liu, S. A. Chayong, D. Kirkwood, "Thixoforming of normally wrought aluminium alloys", Materrials Science Forum, vol. 396-402, pp. 131-136, 2002.

[12] E.J. Zoquia, M. Paesa, E. Es-Sadiqi, "Macro- and microstructure analysis of SSM A356 produced by electromagnetic stirring", Journal of Materials Processing Technology, vol. 120, pp. 365–373, 2002.

[13] Haga, T., "Semi-solid roll casting of aluminum alloy strip by melt drag twin roll caster", Journal of Materials Processing Technology, 111:64-68(2001-2).

[14] T. Haga, and P. Kapranos, "Billetless Simple Thixoforming Process", Journal of Materials Processing Technology, Vol.130–131, pp. 581–586, 2002.

[15] T. Haga, S. Suzuki, "Casting of aluminium alloy ingots for thixoforming using a cooling slope", Journal of Materials Processing Technology, vol. 118 (1-3), pp. 169-172, 2001.

[16] F. Taghavi, A. Ghassemi, "Study on the effects of the length and angle of inclined plate on the thixotropic microstructure of A356 aluminum alloy", Materials and Design, vol. 30, pp. 1762–1767, 2009.

[17] S. Salarfar, F. Akhlaghi and M. Nili-Ahmadabadi, "Influence of Pouring Conditions in the Inclined Plate Process and Reheating on the Microstructure of the Semi-solid A356 Aluminum Alloy", Proceedings of the 8th International Conference on the Processing of Semi-solid Alloys and Composites, 2004.

[18] A. H. Ardakan, X. Liu, F. Ajersch, X. G. Chen, "Wear behaviour of hypereutectic Al–Si–Cu–Mg casting alloys with variable Mg contents," Wear, vol. 269, pp. 684–692, 2010.

[19] M. Zeren, E. Karakulak, S. Gümüs, "Influence of Cu addition on microstructure and hardness of near-eutectic Al- Si-xCu-alloys," Trans Nonferrous Met. Soc. China, vol. 21, pp. 1698-1702, 2011.

[20] T. Savaskan, Y. Alemdag, "Effect of nickel additions on the mechanical and sliding wear properties of Al–40Zn–3Cu alloy," Wear, vol. 268, pp. 565–570, 2010.

[21] N. V. Thuonga, H. Zuhailawatia, A. S. Anasyidaa, T. D. Huyb, B. K. Dhindawc, ''Dry wear behavior of cooling-slope-cast hypoeutectic aluminum alloy'', International Journal of Materials Research, www.hanser-elibrary.com by Kungliga Tekniska Högskolan on March 15, 2016.

[22] S. D. Kumar, P. R. Vundavilli, S. Mantry, A. Mandal, M. Chakraborty, ''A Taguchi Optimization Cooling Sloope casting process parameters for production of semi-solid A356 alloy and A356-5TiB_2 in stu composite feedstock,'' Procedia Materials Science, vol. 5, pp. 232 – 241, 2014.

[23] H. Khosravi, F. Akhlaghi, ''Comparison of microstructure and wear resistance of A356−SiCp composites processed via compocasting and vibrating cooling slope'' , Trans. Nonferrous Met. Soc. China, vol. 25, pp. 2490−2498, 2015.

[24] H. Saghafian, S. G. Shabestari, M. H. Ghoncheh, F. Sahihi, "Wear Behavior of Thixoformed Al-25 wt% Mg2Si Composites Produced by Slope Casting Method," Tribology Transactions, vol. 58, pp. 288-299, 2015.

[25] M.,Çolak, D. Dışpınar, "Taguchi Approach for Optimization of Parameters that Effect Grain Size of Cast A357 Alloy," Archives Of Foundry Engineering, vol. 17(4), pp. 35-42, 2005.

Dr. Murat ÇOLAK; He still an academic member of the Mechanical Engineering Department at Bayburt University in TURKEY. His major areas of interests are: Material Science, Manufacturing Process, Casting, Modeling, Casting Simulation and Image Analysis.

Dr. Salih Hakan YETGİN; He is an academic member of the Mechanical Engineering Department at Kütahya Dumlupınar University in TURKEY. His major areas of interests are: Material Science, Polymer materials, Wear behavior of materials, Production and characterization of polymer foam materials.