Genetic Algorithm Optimization of Sand Casting Process Parameters On the Fatigue Strength of Recycled Petrol Generator Pistons

B. N. G. Aliemeke*‡, M. H. Oladeinde**‡

* Department of Mechanical Engineering, School of Engineering, Auchi Polytechnic, Nigeria

** Department of Production Engineering, Faculty of Engineering, University of Benin, Nigeria

(aliemeka@yahoo.com, moladeinde@uniben.edu)

‡ Auchi Polytechnic, School of Engineering Auchi, P.M.B. 13 Auchi, Nigeria, Tel: +2348030648051,

aliemeka@yahoo.com

Received: 06.03.2020 Accepted:26.03.2020

Abstract- Engine components are necessary for smooth running of generators, vehicles and various kinds of locomotives. One of the most important parts of an automobile engine is the piston. The piston of an engine converts thermal energy generated in the combustion chambers into mechanical energy necessary for power transmission. Aluminum alloys reputed for lightness in weight and good conductivity are mostly used in the production of pistons. The design of experiment employed in the production of the piston is the Taguchi Orthogonal array method. It provided a platform on which the various experimental conditions were observed. Sandcasting was used in the production of pistons. Mathematical model was developed using Multiple Linear Regression technique and ANOVA test was carried out to ascertain the developed model adequacy. The model was adjudged adequate with an adjusted R2 of 99.85%. Signal-to-noise ratio technique was used to determine the optimal level of the process parameters which are 750oC, 49.998Hz and 30.01 seconds for pouring temperature, vibration frequency and vibration time respectively. Furthermore, the developed model was used as objective function in the Genetic algorithm tool box and the result obtained was in consonance with that obtained in Signal-to-noise ratio technique. In confirmation of test carried out it was noticed that the actual experimental values were similar to that predicted by the model.

Keywords Genetic algorithm, sand casting, Design of experiment, Taguchi, Signal-to-noise ratio.

Özet- Motor bileşenleri, jeneratörlerin, araçların ve çeşitli lokomotiflerin düzgün çalışması için gereklidir. Bir otomobil motorunun en önemli parçalarından biri pistondur. Bir motorun pistonu, yanma odalarında üretilen termal enerjiyi güç iletimi için gerekli mekanik enerjiye dönüştürür. Ağırlıkta hafiflik ve iyi iletkenlik ile tanınan alüminyum alaşımları çoğunlukla piston üretiminde kullanılır. Pistonun üretiminde deneysel tasarımlarda Taguchi Ortogonal dizi yöntemi kullanılmıştır. Bu dizi yönetimi çeşitli deney koşullarının gözlemlendiği bir platform sağladı. Piston üretiminde kumlama kullanılmıştır. Matematiksel model, Çoklu Doğrusal Regresyon tekniği kullanılarak geliştirilmiş ve geliştirilen model yeterliliğini belirlemek için ANOVA testi yapılmıştır. Model,% 99.85'lik bir ayarlanmış R2 ile yeterli şekilde kararlaştırıldı. Dökme sıcaklığı, titreşim frekansı ve titreşim süresi için sırasıyla, 750oC, 49.998Hz ve 30.01 saniye olan işlem parametrelerinin optimum seviyesini belirlemek için sinyal-gürültü oranı tekniği kullanılmıştır. Ayrıca, geliştirilen model Genetik algoritma araç kutusunda objektif fonksiyon olarak kullanılmış ve elde edilen sonuç Sinyal-gürültü oranı tekniğinde elde edilen sonuçla uyumlu bulunmuştur. Gerçekleştirilen testin onaylanmasında, gerçek deneysel değerlerin, modelin öngördüğü değerlere benzer olduğu görülmüştür..

Anahtar Kelimeler Genetik algoritma, kum dökümü, Deney tasarımı, Taguchi, Sinyal-gürültü oranı.

1. Introduction

The piston is considered as one of the most critical components of an internal combustion engine [1]. It is the engine part that receives the energy from combustion of fuel and air in the combustion chambers before transmitting it to the crankshaft [2]. It utilizes heavy stresses under severe temperature condition [3]. It is apparent that pistons been one of the most stressed components face the risk of early failure in engines [4]. It is apparent from the automobile combustion of the fluids that the piston component in the internal combustion engine and designers it may impede on the smooth working plan of an entire mechanical system.

In analyzing the effect of mechanical properties on internal combustion engine pistons, [13] examined the ultimate yield strength of Al-GHS 1300. The study showed that the aluminium alloy posses a very high ultimate yield strength of about 1300Mpa when compared to other aluminium alloy and composites. [14] investigated the effect of alloying elements on the mechanical properties of Aluminium-silicon piston alloys. The needle shaped silicon in the structural matrix of Al-Si alloys exhibits improved mechanical properties when heat treated in the presence of various alloying elements. The study investigates the effect of silicon on the hypoeutectic, eutectic and hypereutectic aluminium piston alloys. The result of the study reveals that higher Si content of the hypereutectic piston alloy contributes to the high ultimate tensile strength and hardness of aluminium silicon alloys. It also reveals that mechanical properties increase with silicon content. The process parameters examined in this study are pouring temperature, vibration frequency and vibration time. The response variable investigated in this study is the fatigue strength of the aluminium alloy. The quality of aluminium used in producing engine pistons is Silumin[15]. In this study scraps of Yamaha 950 Tiger generator pistons of the Silumin quality will be used to produce the 0.67hp piston. The study will determine the optimal values of sand casting parameters on the fatigue strength of recycled 0.67Hp generator pistons.

2. Material and Methods

The materials used in this study are Frequency meter, graphite crucible furnace, stopwatch, aluminium alloy piston scraps, fatigue strength testing machine and CNC lathe machine. The experiment was carried out by adhering to the process parameters and their various levels as shown in Table 1.

Table 1. Process parameters and their various levels

Process parameters	LEVELS		
	L1	L2	L3
Pouring temperature, A (^{0}C)	700	725	750
Vibration Frequency, B(Hz)	10	30	50
Vibration time, C (seconds)	30	45	60

In carrying out the recycling experiment sand casting was used in developing the pistons. Taguchi method was the Design of Experiment employed in creating a layout for the experiment [16]. The Taguchi L9 orthogonal array was prescribed by the Minitab 17 software for a 4 process parameters and 3 level arrangements [17]. A total of 9 different experiments were conducted. The process parameters and the levels were inputted in the experimental matrix designed by the Taguchi method. Scrap aluminium alloy pistons were collected and recycled through the sand casting method. The scrap pistons were charged into crucible furnace and heated to a molten state of 7600C as indicated by a digital thermocouple. The molten metal was scooped from crucible containing the molten alloy and transferred to into the sand mould on mechanical mould vibrating machine for grain refinement. The vibration was done at various frequencies 10Hz, 30Hz and 50Hz as produced by an attached variable frequency machine. Nine experiments were conducted and the resultant sand castings were subjected to specimen preparation using lathe machine. In this study Signal-To-Noise ratio was employed to compute the optimal parametric setting. The highest value of the signal -to-noise ratio was regarded as the optimal level of the parameter [18].

The fatigue test machine was used to conduct the fatigue test. The machine consists of a shaft, digital counter, a flat metal base and bearing housing. A set of well machined cast aluminium alloy specimens of ASTM-E466-82 shown in Figure 2 were fit into the load bearing end and the motor shaft end with the aid of a pipe wrench. The power knob was switched on so as to rotate the fixed specimen at a uniform speed. The installed counter on the machine recorded the number of cycles at which the specimen failed. Variable loads (weights) were used for the experiment. At the end of the experiment the stress to number of cycles to failure (S-N) curves were constructed. The applied stress, σ was calculated by using load P(N) in the equations 1 and 2.

$$\sigma = \frac{My}{I} \quad (1)$$

$$\sigma = \frac{125.7P \times 32}{\pi \times D^3} \quad (2)$$

Where P = load in Newtons

D=diameter of specimen in millimetres. In this study 5.5mm was used.

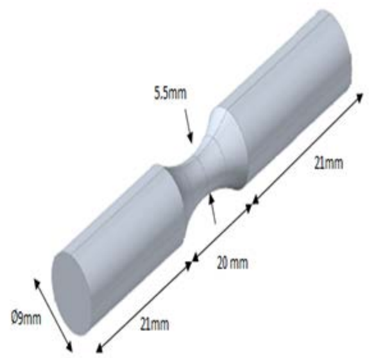


Fig. 1. Fatigue test specimen.

3. Result and Discussion

3.1. Taguchi Orthogonal Array and The Signal to Noise(S/N) Ratio Analysis for Fatigue Strength

The fatigue strength test and Signals to noise ratio values are displayed in Tables 2 and 3. The optimal values for the process parameters are shown in the signal to noise ratio main effect plot represented by Figure 3. The optimal values for pouring temperature, vibration frequency and vibration time as shown in Figure 3 are $750°C$, 50Hz, and 30 secs respectively.

Fig. 2. Fatigue test specimens.

Table 2. Fatigue Test Experimental Values and their Corresponding Signal to Noise Ratios

Experiment No.	Random Order of Experiment	Pouring Temperature, A(^{0}C)	Vibration Frequency, B(Hz)	Vibration Time, C (secs)	Fatigue stress, F(kpa)	Number of cycles($\times10^3$)		Signal to noise ratio (db)
						Trial 1	Trial 2	
1	2	700	10	30	123000	19.5	20.0	101.798
2	5	700	30	45	132000	15.8	16.0	102.411
3	7	700	50	60	141000	12.2	12.0	102.984
4	8	725	10	45	159000	7.2	6.8	104.028
5	3	725	30	60	171000	5.2	5.0	104.660
6	1	725	50	30	194000	2.6	2.5	105.756
7	6	750	10	60	201000	1.4	1.5	106.064
8	9	750	30	30	220000	0.45	0.5	106.848
9	4	750	50	45	231000	0.12	0.1	107.272

Table 3. Signal to noise ratio for fatigue strength with respect to factor levels

Level	**Pouring temperature, A(^{0}C)**	**Vibration frequency, B(Hz)**	**Vibration time,C (seconds)**
1	102.4	104.0	104.8
2	104.8	104.6	104.6
3	106.7	105.3	104.6
Delta	4.3	1.4	0.2
Rank	1	2	3

The main effect plot for signal to noise ratio and mean is shown in Figure 3.

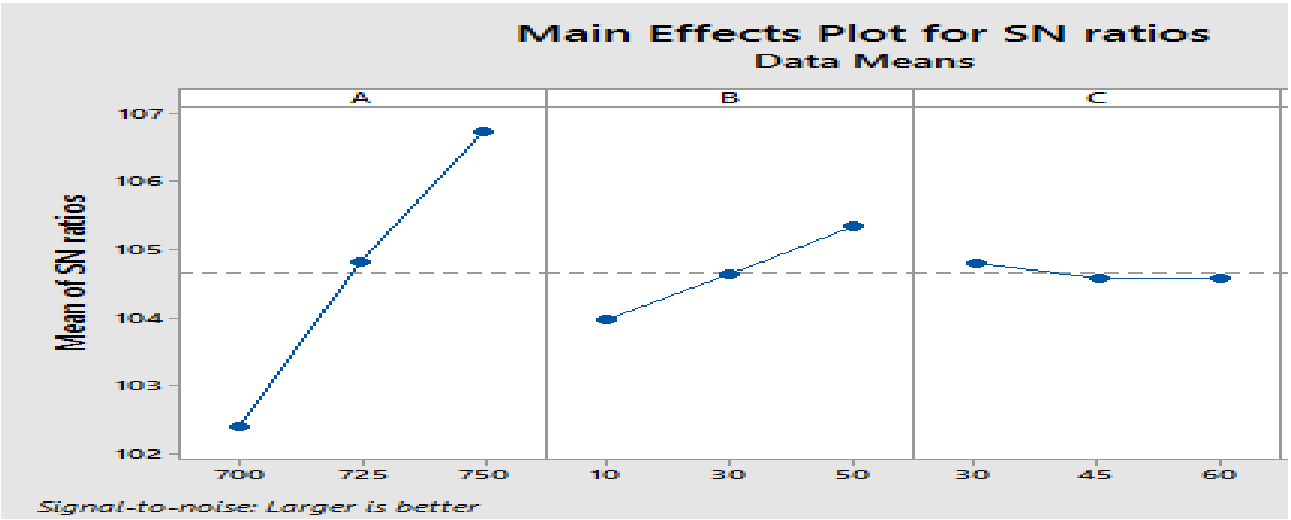


Fig. 3. Main effect plot for signal to noise ratio of fatigue strength process parameters.

The developed fatigue strength model is given as

$$F = -1071417 + 1706.7A + 691.7B - 266.7C \quad (3)$$

The significance test for the fatigue strength model is shown in Table 4.

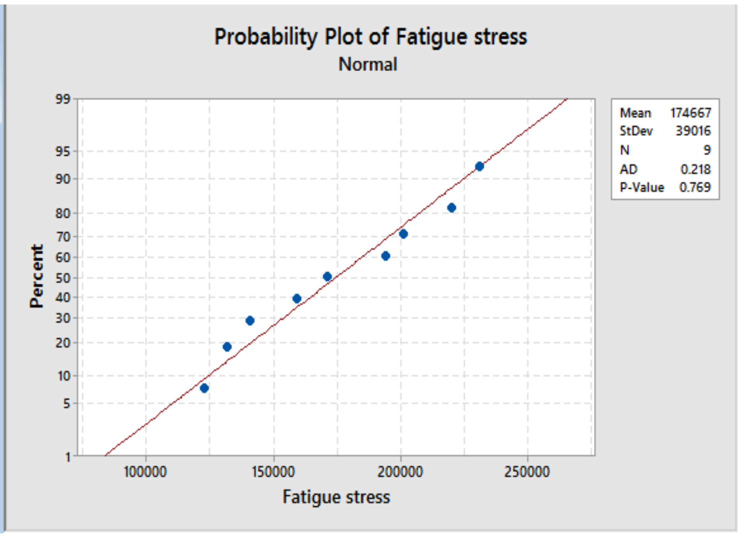
Table 4. Significant test for fatigue strength model

Term	Coef	SE coef	T-value	P-value
Constant	-1071417	17818	-60.13	0.000
A	1706.7	24.4	69.93	0.000
B	691.7	30.5	22.67	0.000
C	-266.7	40.7	-6.56	0.001

Also, Analysis for variance (ANOVA) was used to test for the adequacy of the fatigue strength regression model. Table 5 shows the ANOVA result from Minitab 17 software.

Table 5. ANOVA adequacy test for fatigue strength model

Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	3	12166833333	4055611111	1815.95	0.000
A	1	10922666667	10922666667	4890.75	0.000
B	1	1148166667	1148166667	514.10	0.000
C	1	96000000	96000000	42.999	0.001
Error	5	11166667	2233333		
Total	8	12178000000			



The model has all 3 process parameters. significant and R2=99.91% and R2(adj)=99.85%. A further adequacy test using normal probability plot is shown in Figure 4. **Fig. 4.** Normal probability plot for fatigue strength test value.

The normality test plot shown in Figure 4 indicates that the fatigue test data are normally distributed and the residual points are very close to the ideal normal distribution diagonal line. Also, the Anderson-Daling value and the p- value which are 0.218 and 0.769 show insufficient evidence for any deviation which goes to show that the data are normally distributed.

3.2. Genetic Algorithm Analysis on Fatigue Strength

The mathematical model obtained through multilinear regression was used as objective function in the MATLAB genetic algorithm tool [19]. A population size of 50 was used and the number of variable is 4. Crossover and mutation probability employed was 85% and 0.01 respectively. Also, a stall time of 100 seconds and 100 generations were used for the optimization.

Lower bound of parameters = {700, 10, and 30}

Upper bound of parameters = {750, 50, and 60}

The Figure 5 and Table 6 shows the level range and optimal levels for the parameters used in the fatigue strength mathematical model as obtained from the MATLAB genetic algorithm tool. The fitness function value for the fatigue strength as given by genetic algorithm is 236024kpa.

Table 6. Result of optimal levels of process parameters from genetic algorithm

Factor	Parameters	Level range	Optimal level
A	Pouring temp (^{0}C)	700-750	749.995
B	Vibration frequency(Hz)	10-50	49.997
C	Vibration time(secs)	30-60	30.010

3.3. Comparison Between Taguchi and Genetic Algorithm for the Fatigue Strength Result

The Tables 7 and 8 show the comparison between the results obtained from Taguchi and genetic algorithm methods of optimization. The result showed high level of similarity among the process parameters. Also there was little difference in the response variable.

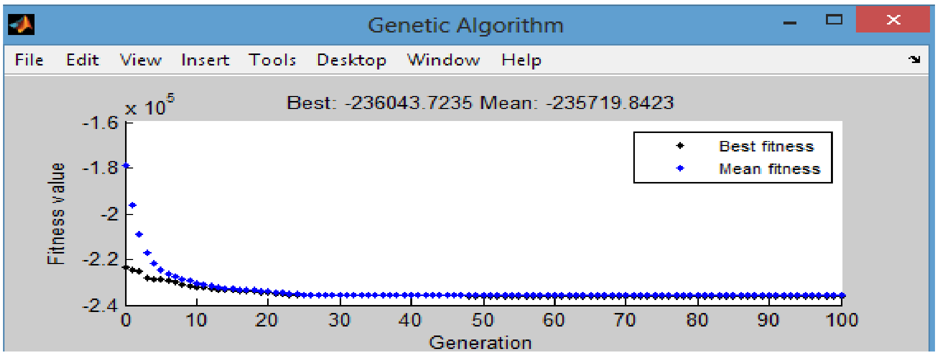


Fig. 5. Genetic algorithm plot for the fatigue strength fitness value and its variables.

Table 7. Comparison between Taguchi and Genetic algorithm result of process parameters

Factor	Process parameters	Taguchi method	Genetic algorithm
A	Pouring temperature A(^{0}C)	750	749.99
B	Vibration frequency B,(Hz)	50	49.99
C	Vibration time (sec)	30	30.01

Table 8. Comparison of Taguchi and Genetic algorithm result for fatigue strength model

S/N	Response variable	Taguchi method	Genetic algorithm
1	Fatigue strength(kpa)	236667	236024

3.4. Stress to Number of Cycles (S-N) curve for Fatigue Strength

The fatigue strength of aluminum alloys and ferrous metals are mostly analysed with the aid of the S-N curve [20]. A vivid classification of fatigue life was done in the study. The relationship between the fatigue stress and the number of cycles to failure showed that the higher the load/stress the lower the number of cycles to failure.

With reference to the experimental data shown in Table 2 a scattered plot for the fatigue stress and the number of cycles was obtained. It was noticed from the scattered plot in Figure 6 that the higher the stress applied the lower the number of cycles to failure attained.

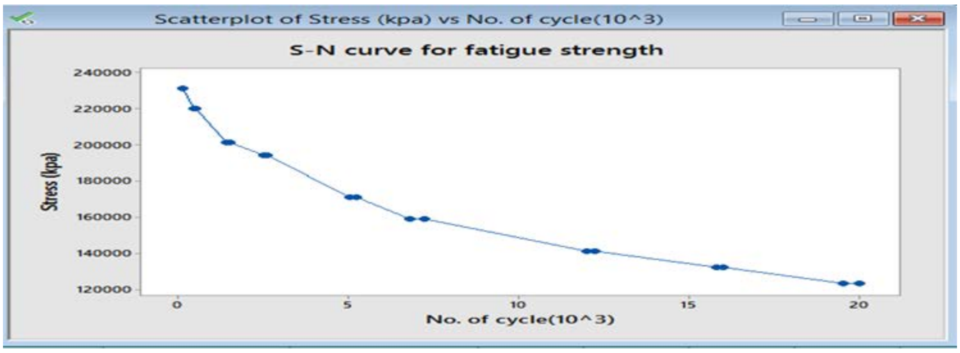


Fig. 6. Scattered plots for S-N curve for fatigue strength variables.

3.5. Confirmatory Test

The optimal levels of the process parameters obtained from the evolutionary Genetic algorithm were used to produce pistons in the foundry. The optimal pouring temperature of $749.9980°C$, vibration frequency of 49.999Hz and vibration time of 30.01seconds were used for sand casting and the fatigue strength result obtained from the actual experiment had similar value with the predicted value from the developed mathematical model.

4. Conclusion

Taguchi orthogonal array method was used to develop a layout for the production of the pistons. The pistons were sand cast and the fatigue strength response determined through fatigue test experiment. And also the lower the load/stress applied the higher the number of cycles to failure. Linear model was developed using multiple linear regression method and the model was adjudged adequate by the ANOVA test conducted. The optimal levels determined were used to sand cast pistons. A confirmatory test carried out showed that the response value obtained from the actual experiment was similar to the predicted value of the model.

References

[1] P. Carvelheira, and P. Goncalves, "FEA of Two Engine Pistons made of Aluminium Cast Alloy 390 and Ductile Iron 65-45-12 under Service Conditions". 5th International Conference on Mechanics and Materials in Designs, Porto, pp.12-24, July, 2006.

[2] M. D. Rohrle, Pistons for Industrial Combustion Engines,1st ed., Vol. 1. Stuggart: Verleg Modern Press, 1995 pp. 24-34.

[3] M. F. Ashby, "The deformation of plastically non-homogeneous materials", Philosophical Magazine,Vol. 21, pp. 399–424, 2005.

[4] S. Srivathsan, "Comparative Study of Aluminium Alloy Pistons Manufactured by Casting and Powder Forging", International Journal of Scientific and Engineering Research, Vol. 5, No.6, pp.662-665, 2014.

[5] J. Heuer, "Development and Testing of Carbon Pistons". Structured Materials Research Institute, Stuggart, Germany. 2015

[6] L. J. Yang, "The Effect of Casting Temperature on the Properties of Squeeze Cast Aluminium and Zinc Alloys", Journal of Materials Processing Technology, Vol. 2, No. 14, pp. 391-396, 2003

[7] F. U. Ozioko, "Synthesis and Study on Effect of Parameters on Dry Sliding Wear Characteristics of Al-Si Alloys". Leonardo Electronic Journal of Practices and Technologies, No. 20, pp.39-48, 2012.

[8] A. I. Al-Mosawi, M. Rijab, S. A. Abdulsada and R. K. Ajmi, "Recycling of Aluminium Castings", Ecronicon Chemistry Journal, Vol. 2, No.1, pp 48-55, 2015.

[9] J. Cui, and J. H. Roven, "Recycling of Automotive Aluminium", Norwegian University of Science and Technology Norway, 2015.

[10] O. O. Ajibola, and D. T. Olorutoba, "Wear and corrosion of cast AI Alloy Piston with and without Brake Oil", Indian Journal of materials, Science, Vol. 10, pp. 1 – 10, 2015.

[11] M. O. Durowoju, I. A. Babatunde, W. A. Raheem, and M. T. Ajala, "Effect of Antimony on the Tensile Strength and the Morphology of Si Platelets in Recycled Aluminium Pistons Alloys", Journal of Material Science and Engineering, Vol. 3, No. 2 pp. 1 – 6, 2014

[12] B. Atzori, G. Meneghetti, and M. Ricotta, "Analysis of the Fatigue Strength under two Load Levels of a Stainless Steel Based on Energy Dissipation", EDP Sciences Vol. 6, pp. 1-8, 2013

[13] T. Akhil, K. Naresh, A. Khurshid, and P. A. Kumar, "Analysis on Four Stroke Single Cylinder Engine Piston by using Aluminium Alloys (AI – GHS 1300, Al-SiC-Graphite A6061 Pure Aluminium)". International Journal of Mechanical engineering, Vol. 3, No. 1, pp. 4 – 13, 2016.

[14] B. Mathai, C. Mathew, K. Pratheesh, and C. K. Varghese, "Effect of Silicon on Microstructure and Mechanical Properties of Al-Si Piston Alloys", International Journal of

Engineering Trends and Technology, Vol.29, No.6, pp.299-305, 2015

[15] K. Vengatesvaran, N. Prithiviraj, and N. Periyasamy. "Thermal Analysis and Material Optimization of Piston in I.C. Engine", IJARIIE, Vol. 4, No. 3, pp. 153-171, 2018.

[16] M. N. Nekere, and A. P. Singh, "Casting process by using Taguchi̇s Robust Design Method", International Journal for Quality Research, Vol. 6. pp 3-6, 2012.

[17] M. Jayaram, "Parameter Optimization of WEDM for AA6061 Using Genetic Algorithm", International Research Journal of Latest Trends in Engineering and Technology, Vol.2, No.3, pp. 96-104, 2015

[18] G.G Patil and K. H. Inamadar, "Optimization of Casting Process Parameters Using Taguchi Method", International Journal of Engineering Development and Research, Vol.2, No.2, pp.2506-2512, 2014

[19] M. T. Azhagan, B. Mohan and A. Rajadurai, "Optimization of Process Parameters to Enhance the Hardness on Squeeze Cast Aluminium Alloy AA6061", International Journal of Engineering and Technology, Vol.6, No.1, pp. 183-190, 2014.

[20] K. Girija, and I. Satyanarayana, "Improved Mechanical Properties and Microstructure of Mechanical Vibration Mold During Solidification", International Journal Advanced Research in Management, Architecture, Technology and Engineering, Vol.1, No.4, pp. 1-3, 2015