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Effect of Uncarbonized Eggshell Weight Percentage on Mechanical Properties of Composite Material Developed by Electromagnetic Stir Casting Technique

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ABSTRACT

This study deals with the effect of uncarbonized eggshell weight percentage on the tensile strength of AA 2014 composite manufactured by Electromagnetic stir casting technique. Response surface methodology (RSM) is used to design the experiment. The selected process parameters are preheat temperature, stirring current, stirring time, matrix pouring temperature, and reinforcement of uncarbonized eggshell weight percentage. Analysis of variance (ANOVA) is employed to study the influence of selected process parameters. The maximum tensile strength of 287.194 MPa was achieved for reinforcement preheat temperature 537.87 °C, stirring current 12 A, stirring time 179.9 sec, matrix pouring temperature 726.8 °C, and reinforcement weight percentage of 12.46. At optimum level of process parameter confirmation tests are performed to validate the result. In confirmation test, tensile strength and hardness are investigated. It is observed that due to the reinforcement of uncarbonized eggshell in AA2014 aluminium alloy, tensile strength and hardness are improved by 55.24 % and 39.58 %.

1. INTRODUCTION

Chicken eggshells are an industrial byproduct containing 95 % calcium carbonate [1]. Indian food industries are generating a huge amount of about 20,000 tons of waste eggshell every year [2]. Newly, green manufacturing technique has evolved a revolution in the field of manufacturing of composite material [3]. Currently industrial waste such as ground nut, waste eggshell, bamboo leaf, bones of animal /human body skelton, flyash etc. are used as a reinforcement material for the preparation of composite [4-6]. Composites are formed by reinforcing the ceramic particles in the melt [7-8]. Through various research articles, it is illustrated that the improvement in mechanical properties is observed due to the reinforcing of various ceramic particles like Al_2O_3, SiC, B_4C, TiC and TiB_2 etc [9-11]. The traditional electromagnetic stir casting process is used to develop the aluminum metal matrix composite.

Figure 1. Waste eggshell producing soil pollution [2]

Figure 1 shows the waste eggshell source from Chhattisgarh, Waste Management [2]. It was observed that lots of soil pollution produces from waste eggshell. These eggshells degrade lots of agricultural land fertility. However, by utilizing waste eggshell in development of new materials, some soil pollution can be reduced [12-14].

Boronat et al. [15] have developed bio composite of polyethylene as matrix material and eggshells as reinforcement material. Thermal, mechanical, and rheological properties ware investigated in this research work. Due to the reinforcement mechanical properties (tensile modulus, flexural hardness and stiffness) were significantly improved. Toro et al. [1] have conducted experimental studies to evaluate the effect of eggshells filler on mechanical properties of polypropylene composite. Significant improvement in the Young's modulus (E) was observed. Hassan et al. [3] have investigated the effect of eggshells reinforcement on mechanical properties and microstructure of Al–Cu–Mg based composite. Ashok et al. [16] have generated biodegradable composite of poly (lactic acid) (PLA)/ eggshell powder through composite film casting method. It was observed that mechanical properties of PLA material were increased due to the addition of eggshells up-to 4 %. However, beyond 4 % of eggshells reinforcement inverse effect was observed. Parande et al. [17] have fabricated Mg–2.5 Zn magnesium alloy matrix based composite using eggshells as reinforcement. Results of experimental studies show that mechanical and thermal properties of fabricated composite were improved.

From literature review it can be concluded that very few research works were carried out to investigate the impact of uncarbonized eggshell reinforcement on mechanical properties of AA 2014 metal matrix composite. In this research work, response surface methodology (RSM) was used to optimize the electromagnetic stir casting process parameter for the fabrication of composite. The electromagnetic process parameters used in this work are preheat temperature, stirring current, stirring time, matrix pouring temperature, and reinforcement of uncarbonized eggshell weight percentage. At optimum level of process parameter other mechanical properties viz., hardness, toughness and ductility are also investigated. The novelty of this research work lies in the fact that no such study was carried out to optimize the electromagnetic stir casting process parameters in the archival literature.

2. MATERIALS AND METHODS

2.1 Materials and methods

Table 1. Chemical composition of AA2014 Alloy (wt.%)18]

S. No.	Elements	Wt.%
1	Cu	3.9 - 5
2	Fe	0.5
3	Si	0.5-0.9
4	Cr	0.1
5	Ni	0.1
6	Ti	0.2
7	Zn	0.25
8	Mg	0.2-0.8
9	Mn	0.4-1.2

In this study, AA2014 aluminium alloy was chosen as matrix material. AA 2014 aluminium alloy also known as Al-Cu-Mg alloy. It is widely used in air craft industries and automobile sector due to its light weight and good strength. The chemical composition and mechanical properties of AA2014 aluminium alloy are shown in Table 1 and Table 2 respectively [18].

Table 2. Measured properties of AA 2014 Alloy

S. No.	Properties	Values
1	Toughness (Joule)	12
2	Hardness (BHN)	60
3	Tensile Strength (MPa)	185
4	Theoretical density (g/cm^3)	2.8
5	Melting point	640 ℃

2.2 Reinforcement material

In the present investigation, waste eggshell powder was selected as a reinforcement material. Hen's eggshell contains 94 wt. % of $CaCO_3$, 1 wt. % of magnesium carbonate, 1 wt. % of calcium phosphate and rest 4 wt. % of organic matter. For the preparation of the reinforcement particle west eggshells were collected from the egg shops. Eggshells were wash and sundried for 4-5 days in order to remove the moisture content from the surface of eggshells. Dry eggshells were ball milled to obtain the eggshells power. Eggshells powers are passed through multi sieves to obtain a particle range of reinforcement eggshells power [19].

2.3 Development of composite by electromagnetic stir casting process (EMS)

Table 3. Design matrix table for tensile strength

Std order	Run	Reinforcement preheat temperature (Degree Centigrade): A	Stirring Current (Ampere): B	Stirring Time (Seconds): C	Matrix Pouring Temperature (Degree Centigrade): D	Reinforcement Weight Percent (%): E	Tensile Strength (MPa)
21	1	600	9	120	800	16.6058	291
24	2	600	9	120	800	7.5	265.7
11	3	400	6	60	700	2.5	231
17	4	600	9	229.2696	800	7.5	273.2
8	5	400	12	60	900	12.5	274
2	6	800	6	180	900	2.5	238
9	7	800	6	180	700	12.5	285
10	8	400	12	180	900	2.5	249
16	9	600	9	10.73038	800	7.5	263.8
5	10	800	12	60	700	12.5	286
26	11	600	9	120	800	7.5	265.25
19	12	600	9	120	982.116	7.5	255.6
25	13	600	9	120	800	7.5	265.75
3	14	400	12	180	700	12.5	285
20	15	600	9	120	800	-1.6058	231.3
14	16	600	3.536519	120	800	7.5	265
18	17	600	9	120	617.884	7.5	267.5
4	18	800	12	180	700	2.5	247.5
1	19	800	12	60	900	2.5	237.5
23	20	600	9	120	800	7.5	265.4
6	21	800	6	60	900	12.5	275
15	22	600	14.46348	120	800	7.5	270
13	23	964.2321	9	120	800	7.5	254
22	24	600	9	120	800	7.5	265.6
7	25	400	6	180	900	12.5	277
12	26	235.7679	9	120	800	7.5	247

AA 2014/uncarbonized eggshell composite was prepared by EMS. The diagram of stir casting is shown in Figure 2. Response surface methodology was used to design the EMS. Total number of conducted experiments was 26. The range of reinforcement preheat temperature 235.7679 to 964.2321°C, stirring current 3.536519 to 14.46348 A, stirring time 10.73038 to 229.2696 sec, matrix pouring temperature 700 to 982.116 °C, and reinforcement weight percentage lies between and 0 to 16.6058 %. The melt was allowed to cool in the atmospheric air. Specimens were fabricated as per ASTM standard. Design matrix table for performed experiment in shown in Table no. 3.

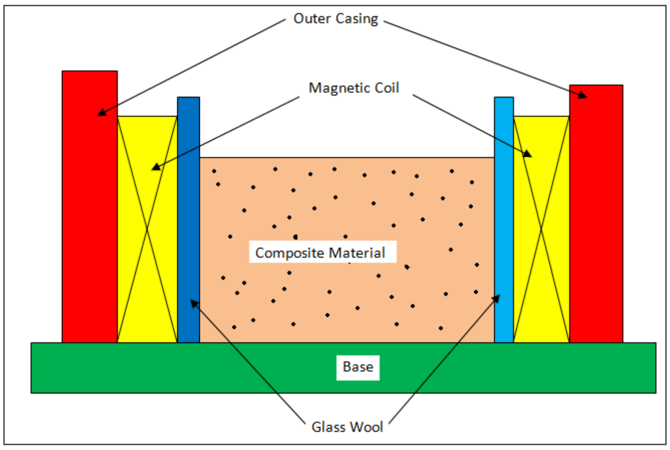

Figure 2. Schematic diagram of electromagnetic stir casting set-up

3. RESULTS AND DISCUSSION

3.1 Mathematical modelling for tensile strength

For statistical analysis, design of experiment (DOE) software was used to develop the regression model. ANOVA Table 4 shows the impact of individual electromagnetic process parameters. The model F-value of the regression equation 1 was 4328.76 implies that developed model was statistically significant. The probability value of the regression model was 0.00001 implies that there was only a 0.01 % chance that model may be insignificant due to the noise factors. The probability value for all the electromagnetic stir casting process parameters were less than 0.0500 indicate model terms were significant. In this case A, B, C, D, E, A^2, B^2, C^2, D^2, E^2, AB, AC, AD, AE, BC, BE, CD, DE were significant model terms. The value of R^2 close to 1 indicates that model was significant. In this investigation value of R^2 was 0.999 and Adj-R^2 was 0.9997 very close to each other implies that there is a good agreement between R^2 and Adj-R^2.

$$\textbf{Tensile Strength} = -5.94314 + 0.36652 \times A + 3.52065 \times B + 0.33903 \times C + 0.28443 \times D + 1.30755 \times E - 1.14862 \times 10^{-004} \times A^2 + 0.059024 \times B^2 + 2.31313 \times 10^{-004} \times C^2 - 1.267278 \times 10^{-004} \times D^2 - 0.055335 \times E^2 - 4.92729 \times 10^{-003} \times A \times B - 3.57450 \times 10^{-004} \times A \times C - 1.72074 \times 10^{-004} \times A \times D + 7.75726 \times 10^{-004} \times A \times E - 5.50165 \times 10^{-003} \times B \times C - 1.30792 \times 10^{-003} \times B \times D + 0.071655 \times B \times E - 1.20900 \times 10^{-004} \times C \times D + 1.22268 \times 10^{-003} \times C \times E + 1.92945 \times 10^{-003} \times D \times E \quad (1)$$

Table 4. ANOVA Table for tensile strength of composite

Source	Sum of Squares	DF	Mean Square	F Value	Prob> F	
Model	**7082.275**	**20**	**354.1137**	**4328.755**	**< 0.0001**	**significant**
A	24.5	1	24.5	299.4928	< 0.0001	
B	12.5	1	12.5	152.8024	< 0.0001	
C	44.18	1	44.18	540.0649	< 0.0001	
D	70.805	1	70.805	865.5341	< 0.0001	
E	1782.045	1	1782.045	21784.06	< 0.0001	
A^2	437.492	1	437.492	5347.987	< 0.0001	
B^2	5.848387	1	5.848387	71.49182	0.0004	
C^2	14.37146	1	14.37146	175.6795	< 0.0001	
D^2	33.04853	1	33.04853	403.9916	< 0.0001	
E^2	39.66273	1	39.66273	484.845	< 0.0001	
AB	26.71155	1	26.71155	326.5272	< 0.0001	
AC	56.23054	1	56.23054	687.3731	< 0.0001	
AD	36.19674	1	36.19674	442.476	< 0.0001	
AE	1.83906	1	1.83906	22.48103	0.0051	
BC	2.997163	1	2.997163	36.63791	0.0018	
BD	0.470528	1	0.470528	5.751829	0.0618	
BE	3.530662	1	3.530662	43.1595	0.0012	
CD	1.60817	1	1.60817	19.65858	0.0068	
CE	0.411197	1	0.411197	5.026556	0.0750	
DE	2.844376	1	2.844376	34.7702	0.0020	
Residual	0.409025	5	0.081805			
Lack of Fit	0.232025	1	0.232025	5.243501	0.0839	not significant
Pure Error	0.177	4	0.04425			
Cor Total	7082.684	25				
Std. Dev.	0.286016	R-Squared	0.999942			
Mean	262.7346	Adj R-Squared	0.999711			
C.V.	0.108861	Pred R-Squared	0.976355			
PRESS	167.4673	Adeq Precision	232.4501			

3.2 Effect of Electromagnetic process parameters on hardness

Selected electromagnetic stir casting process parameters i.e. reinforcement preheat temperature, stirring current, stirring time, the matrix pouring temperature, and reinforcement weight percentage have affected the mechanical properties of prepared Al 2014/ uncarbonized eggshell composite. The influence of each parameter is discussed in the next sub sections.

3.2.1 Effect of uncarbonized eggshell powder preheat temperature on tensile strength of composite

Figure 3 shows that by increasing the eggshell powder preheat temperature up to center value, tensile strength was increased. Reinforcement preheat temperature plays a vital role in the improvement of tensile strength. The maximum tensile strength of 287.194 MPa was found at reinforcement preheat temperature of 608.28 °C (refer figure 9). Beyond this, the decrement of tensile strength was observed. An excessive preheating of eggshell powder may cause illusions which will reduce the tensile strength by the increase of uncarbonized eggshell preheat temperature.

3.2.2 Effect of stirring current of electromagnetic stir casting on tensile strength of composite

Stirring current have influenced the tensile strength of AA 2014/uncarbonized eggshell composite. From Figure 4, it was concluded that increased trend of tensile strength was observed with the increase of stirring current up to an extent. The maximum tensile strength was found to be 287.194 MPa at 12 A current as shown in Figure 9.

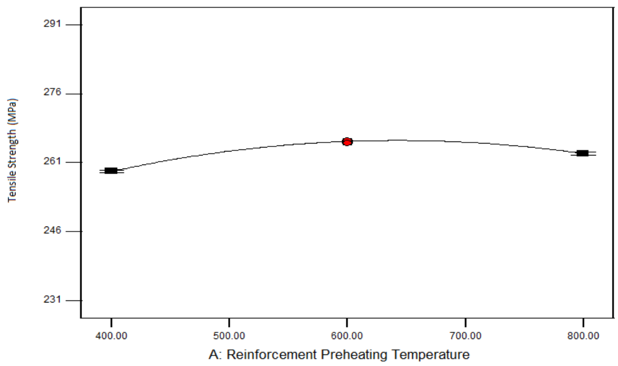

Figure 3. Effect of uncarbonized eggshell powderpreheat temperature on tensile strength of composite

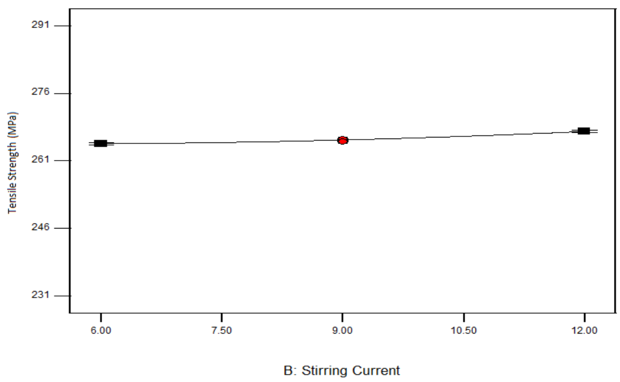

Figure 4. Effect of stirring current of electromagnetic stir casting on tensile strength of composite

3.2.3 Effect of stirring time of electromagnetic stir casting on tensile strength of composite

Stirring time has affected the tensile strength of electromagnetic stir casted composite. It was observed that by increasing the stirring time, tensile strength was improved as shown in Figure 5. The increase of stir time up to an extent had achieved uniform distribution of uncarbonized eggshell in the molten matrix. 287.194 MPa was the maximum tensile strength obtained at stirring time of 178.38 sec as shown in Figure 9.

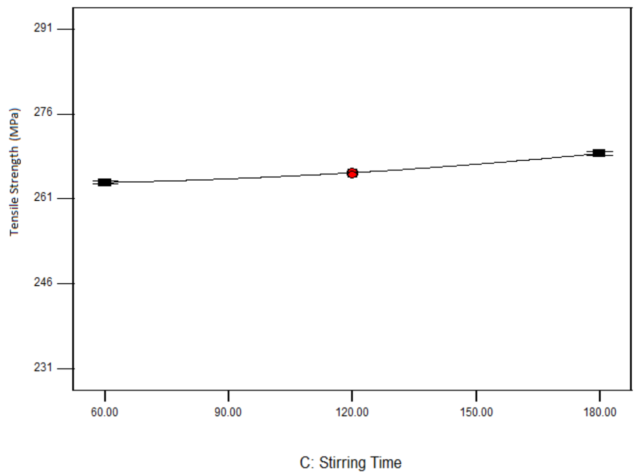

Figure 5. Effect of stirring time of electromagnetic stir casting on tensile strength of composite

3.2.4 Effect of matrix pouring temperature in crucible on tensile strength of composite

With the increase of matrix pouring temperature in crucible, the decreasing trend of tensile strength is shown in Figure 6. This was due to poor interfacial bonding between the uncarbonized eggshell and Al 2014 alloy. The reactant products have formed the envelope nearby the reinforcement have reduced the tensile strength of the composite. The maximum hardness of 287.194 MPa was found at 726.80 °C as shown in Figure 9.

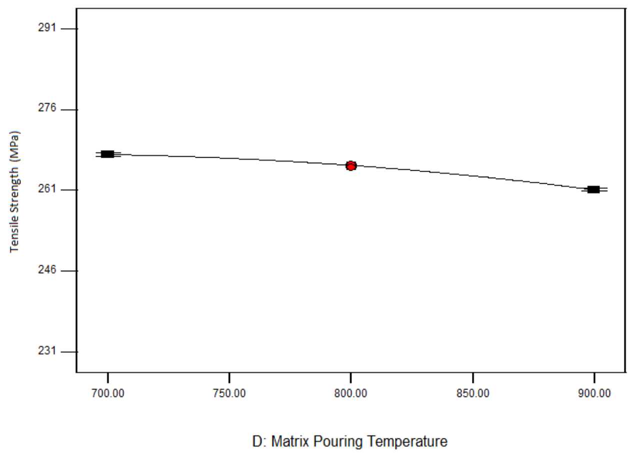

Figure 6. Effect of matrix pouring temperature in crucible on tensile strength of composite

3.2.5 Effect of uncarbonized eggshell powder weight percent on tensile strength of composite

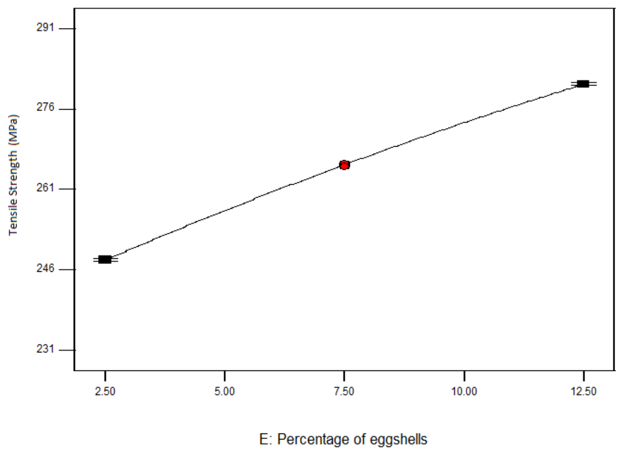

Figure 7. Effect of uncarbonized eggshell powder on tensile strength of composite

It was observed from Figure 7 that 12.5 wt% of uncarbonized eggshell reinforced composite have maximum tensile strength. Below this, the decrement of tensile strength was observed. The powdered uncarbonized eggshell had enhanced the tensile strength of fabricated composite to 287.194 MPa in comparison to Al 2014 alloy, having 185 MPa. Figure 7 clearly demonstrates that the increased trend of tensile strength was obtained up to 12.5 wt% of uncarbonized eggshell.

3.2.6 3D-Interaction of electromagnetic stir casting process parameters on tensile strength

Ramp function graph illustrated that reinforcement preheat temperature, stirring current, matrix pouring temperature, and reinforcement weight percentage have an influence to improve the tensile strength of the fabricated composite. The maximum tensile strength of 287.194 MPa was achieved for reinforcement preheat temperature 608.28 °C, stirring current 12 A, stirring time 178.38 sec, matrix pouring temperature 764.96 °C, and reinforcement weight percentage of 12.5. Interaction plot of electromagnatic stir sacting process parameter s is shown in Figure 8.

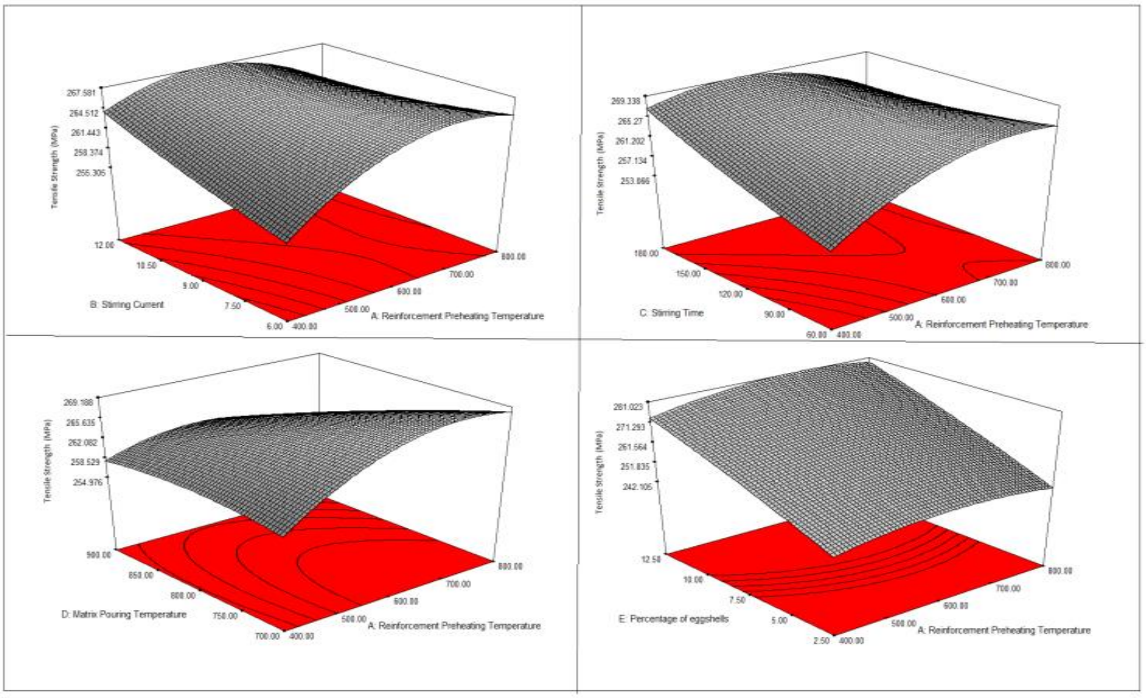

Figure 8. 3D-Interaction of electromagnetic stir casting process parameters on tensile strength

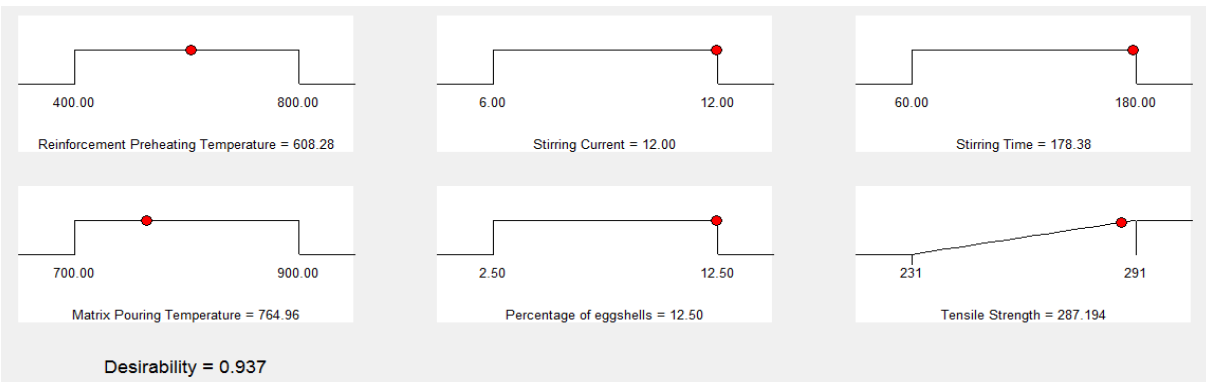

Figure 9. Ramp function graph for tensile strength of composite

3.3 Confirmation experiment

Optical microscopic tests were performed to study the microstructural analysis of the prepared composite at optimum parameters of electromagnetic stir casting process (reinforcement preheat temperature of 537.87 °C, stirring current of 12 A, stirring time of 179.9 sec, matrix pouring temperature of 726.8 °C, and reinforcement weight percentage of 12.46). Figure 10 confirmed the presence of uncarbonized eggshell powder in the matrix. Uniform distribution of uncarbonized eggshell powder was observed in the fabricated composite. Tensile test was conducted to evaluate the tensile strength of AA2014/12.5 wt. % uncarbonized eggshell composite at optimum parameter of electromagnetic stir casting process (reinforcement preheat temperature 608.28 °C, stirring current 12 A, stirring time 178.38 sec, matrix pouring temperature 764.96 °C, and reinforcement weight percentage of 12.5). Average of three tests was performed for all the experiments. Tensile strength value at optimum parameters was found to be 287.194 MPa. At optimum process parameter condition other mechanical properties like hardness, toughness and percentage elongation was also carried out. It was observed that due to the reinforcement of eggshell tensile astength and hardness of AA2014/eggshell composite was improved. However, small amount of decrement in toughness was observed. Percentage elongation of the fabricated composite was decreased.

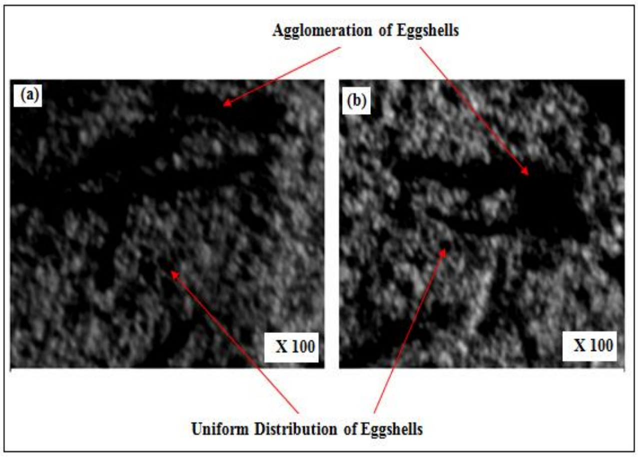

Figure 10. Microstructure of AA2014/12.5 wt. % uncarbonized eggshell powder metal matrix composite

3.4 Mechanical properties of composite at optimum parameters

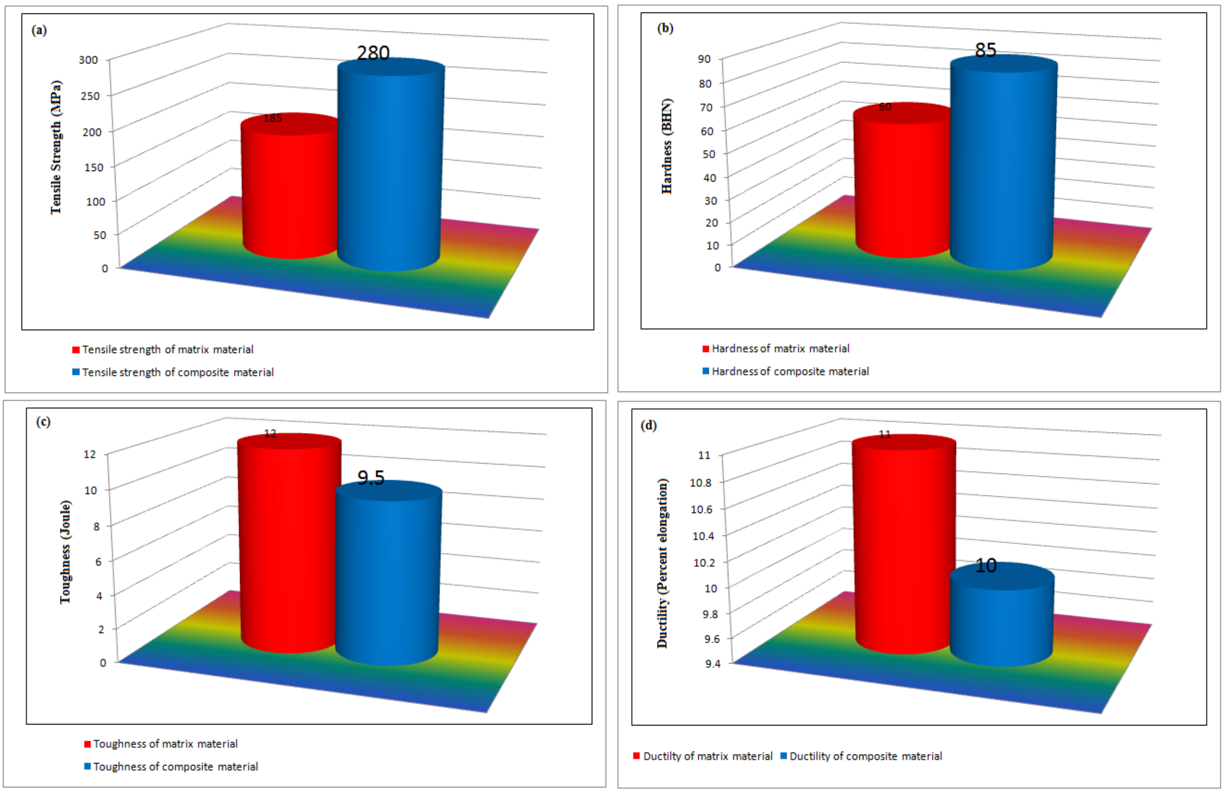

Figure 11. Mechanical properties at optimum electromagnetic stir casting parameters

Confirmation experiment was carried out to see the effects of electromagnetic stir casting parameter effects on mechanical properties of AA 2014/eggshell composite. Figure 11 (a) shows the comparative experimental tensile strength value of composite material developed at optimum parameters and matrix material. Tensile strength was found to be 287.194 MPa for reinforcement preheat temperature 608.28 °C, stirring current 12 A, stirring time 178.38 sec, matrix pouring temperature 764.96 °C, and reinforcement weight percentage of 12.5.246.5 Mpa. Tensile strength at optimum parametrs was found to be 280 Mpa. Tensile strength results showed that there is only 2.55 % error in developed model and experimental result (Figure 11 (b)). Hardness was found to be 85 BHN at optimum parameters. Results showed that about 41.66 % hardness was improved with respect to base matrix material. Though, toughness and ductility were reduced with respect to AA2024 alloy as shown in Figure 11 (c & d).

4. CONCLUSIONS

AA 2014/uncarbonized eggshell composite was successfully developed through electromagnetic stir casting process. Microstructure results have confirmed the uniform distribution of uncarbonized eggshell in the matrix. No porosity was observed in the manufactured composite. The selected parameters reinforcement preheat temperature, stirring current, stirring time, matrix pouring temperature, and reinforcement weight percentage have affected the tensile strength of prepared AA 2014/ uncarbonized eggshell composite through stir casting. The maximum tensile strength of 287.194 MPa was found for reinforcement preheat temperature 537.87 °C, stirring current 12 A, stirring time 179.9 sec, matrix pouring temperature 726.8 °C, and reinforcement weight percentage of 12.46. Tensile strength and hardness was enhanced by 51.35 % and 41.66 % respectively. However the reduction in density and toughness was observed in the fabricated composite.

REFERENCES

[1] Toro, P., Quijada, R., Yazdani-Pedram, M., Arias, J.L. (2007). Eggshell, a new bio-filler for polypropylene composites. Materials Letters, 61: 4347-4350. https://doi.org/10.1016/j.matlet.2007.01.102

[2] Karelia, G. (2018). This Is What Chhattisgarh's Ambikapur, One of the Best Performing Cities in Waste Management, Is Doing with Eggshells, Chhattisgarh, Waste Management. https://swachhindia.ndtv.com/waste-management-chhattisgarh-ambikapur-converts-waste-egg-shells-into-fertilizer-calcium-powder-23338/

[3] Hassan, S.B., Aigbodion, V.S. (2015), Effects of eggshell on the microstructures and properties of Al-Cu-Mg/eggshell particulate composites. Journal of King Saud University - Engineering Sciences, 27(1): 49-56. https://doi.org/10.1016/j.jksues.2013.03.001

[4] Bootklad, M., Kaewtatip, K. (2013). Biodegradation of Thermoplastic starch/eggshell powder composites. Carbohydrate Polymers, 97: 315-320. https://doi.org/10.1016/j.carbpol.2013.05.030

[5] Hassan, T.A., Rangari, V.K., Rana, R.K., Jeelani, S. (2013). Sonochemical effect on size reduction of $CaCO_3$ nano-particles derived from waste eggshells. Ultrasonics Sonochemistry, 20: 1308-1315. https://doi.org/10.1016/j.ultsonch.2013.01.016

[6] Lunge, S., Thakre, D., Kamble, S., Labhsetwar, N., Rayalu, S. (2012). Alumina supported carbon composite material with exceptionally high defluorination property from eggshell waste. Journal of Hazardous Materials, 237: 161-169. https://doi.org/10.1016/j.jhazmat.2012.08.023

[7] Devaraju, A., Kumar, A., Kumaraswamy, A., Kotiveerachari, B. (2013). Influence of reinforcements (SiC and Al_2O_3) and rotational speed on wear and mechanical properties of aluminum alloy 6061-T6 based surface hybrid composites produced via friction stir processing. Materials & Design, 51: 331-341. https://doi.org/10.1016/j.matdes.2013.04.029

[8] Rohatgi, P.K., Kim, J.K., Gupta, N., Alaraj, S., Daoud, A. (2006). Compressive characteristics of A356/fly ash cenosphere composites synthesized by pressure infiltration technique. Composites: Part A; 37: 430-437. https://doi.org/10.1016/j.compositesa.2005.05.047

[9] Sajjadi, S.A., Ezatpour, H.R., TorabiParizi, M. (2012). Comparison of microstructure and mechanical properties of A356 aluminum alloy/Al_2O_3 composites fabricated by stir and compo-casting processes. Materials & Design, 34: 106-111. https://doi.org/10.1016/j.matdes.2011.07.037

[10] Zhao, H.L., Yue, J.S., Gao, Y., Weng, K.R. (2013). Grain and dendrite refinement of A356 alloy with Al-Ti-C-Re master alloy. Rare Metals, 32: 12-17. https://doi.org/10.1007/s12598-013-0021-5

[11] Chen, X., Li, C.W., Wang, J., Li, J., Luan, X.Y., Li, Y., Xu, R., Wang, B.X. (2010). Investigation on solar photocatalytic activity of TiO_2 loaded composite: TiO_2/eggshell, TiO_2/clamshell and TiO_2/$CaCO_3$. Materials Letters, 64: 1437-1440. https://doi.org/10.1016/j.matlet.2010.03.048

[12] Yew, M.C., Ramli Sulong, N.H., Yew, M.K., Amalina, M.A., Johan, M.R. (2013). The formulation and study of the thermal stability and mechanical properties of an acrylic coating using chicken eggshell as a novel bio-filler. Progress in Organic Coatings, 76: 1549-1555. https://doi.org/10.1016/j.porgcoat.2013.06.011

[13] Severa, L., Nemecek, J., Nedomová, S., Buchar, J. (2010). Determination of micromechanical properties of a hen's eggshell by means of nanoindentation. Journal of Food Engineering, 101: 146-151. https://doi.org/10.1016/j.jfoodeng.2010.06.013

[14] Toro, P., Quijada, R., Yazdani-Pedram, M., Arias, J.L. (2007). Eggshell, a new bio-filler for polypropylene composites. Materials Letters, 61: 4347-4350. https://doi.org/10.1016/j.matlet.2007.01.102

[15] Boronat, T., Fombuena, V., Garcia-Sanoguera, D., Sanchez-Nacher, L., Balart, R. (2015). Development of a biocomposite based on green polyethylene biopolymer and eggshell. Materials and Design, 68: 177-185. https://doi.org/10.1016/j.matdes.2014.12.027

[16] Ashok, B., Naresh, S., Obi Reddy, K., Madhukar, K., Cai, J., Zhang, L., VaradaRajulu, A. (2014). Tensile and thermal properties of poly (lactic acid)/eggshell powder composite films. International Journal of Polymer Analysis and Characterization, 19: 245-255. https://doi.org/10.1080/1023666X.2014.879633

[17] Parande, G., Manakari, V., Kopparthy, S.D.S., Gupta, M. (2017). Utilizing low-cost eggshell particles to enhance the mechanical response of Mg-2.5Zn magnesium alloy matrix. Advanced Engineering Material, 09: 1-9. https://doi.org/10.1002/adem.201700919

[18] Durmus, H.K., Meric, C. (2007). Age-hardening behavior of powder metallurgy AA2014 alloy. Materials & Design, 28: 982-986. https://doi.org/10.1016/j.matdes.2005.11.022

[19] Mosaddegh, E.E., Hassankhan, A. (2013). Application and characterization of eggshell as a new biodegradable and heterogeneous catalyst in green synthesis of 7, 8-dihydro-4H-Chromen-5(6H)-Ones. Catalysis Communications, 33: 70-75. https://doi.org/10.1016/j.catcom.2012.12.013