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Assessment of Hardness on AA2014/Eggshell Composite Produced Via Electromagnetic Stir casting Method

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Abstract: Present investigation agreements with the influence of reinforcement on hardness properties of eggshell reinforced AA2014 composite material. Aluminium based composite materials reinforced with eggshell were prepared by electromagnetic stir casting technique (EMS). Experiments were conducted by using Response Surface Methodology (RSM). Uncarbonized eggshell weight percentage, stirring time, matrix pouring temperature, preheat temperature, and stirring current were the selected process parameters. The maximum hardness of AA 2014/eggshell composite are achieved 86.4865 BHN at optimum levels of process parameters i.e. reinforcement weight percentage of 12.5 %, preheat temperature of 600°C, stir time of 3 minutes, matrix pouring temperature at 700 °C, and stirring current of 12 A. Results depicted that uncarbonized eggshell content in AA 2014 alloy had improved the hardness. Confirmation experiment was conducted to verify the result of hardness. It was observed that at optimum level of stir casting method parameter, tensile Strength was also improved. Owing to strengthening of uncarbonized eggshell in AA 2014 alloy, hardness and tensile strength properties was improved by 33.33% and 37.83% respectively.

Keywords: Eggshell, hardness, tensile strength, stirring current, matrix pouring temperature

1. Introduction

Waste eggshells of about 20,000 tones every year is produced in India¹⁾. Waste eggshell produces environment pollution around the residential area. Utilization of waste product in manufacturing tends to the green manufacturing approach²⁾. Common industrial waste like groundnut shell, human body skelton or bones of animal, fly ash, waste eggshell, bamboo leaf etc. are used as a reinforcement material³⁾. Various attempts were made to develop the composite material using these wastes⁴⁾.

Toro et al.⁵⁾ evaluated the influence of eggshells filler on mechanical characteristics of polypropylene composite. Tensile strength of the prepared specimen was investigated. Noteworthy enhancement in the Young's modulus (E) was found. Boronat et al.⁶⁾ developed a bio-based composite of polyethylene with eggshells as reinforcement content. In this study, thermal, mechanical, and rheological ware carried out. It was observed that due to the addition of eggshells as a filler degradation temperature showed a proportional effect. Owing to reinforcement mechanical properties

were improved. Hassan et al.⁷⁾ highlighted the influence of eggshells content on microstructural and mechanical properties of Al-Cu-Mg based composite. Results illustrated that the mechanical characteristics of fabricated composites were improved.

Influence of eggshells and SiC content on stir casted Al 6061/SiC composite was done by Verma et al.⁸⁾. Reinforcement of 5-8 wt.% of eggshell had improved yield strength and compressive strength of Al 6061/SiC composite. Eggshell particles reinforced with Al/Si composite were mechanical tested by Malik et al.⁹⁾. Addition up to 10wt % of eggshell had improved compressive strength and impact energy of the composite. Polypropylene/Eggshell composite was mechanically tested by Lyer et al.¹⁰⁾. Young modulus and yield strength was increased.

From literature survey, it can be observed that due to reinforcement of ceramic particle like SiC, Al₂O₃, TiC, B₄C, and TiB₂ mechanical properties of AA 2014 alloy had improved¹¹⁾. Fig 1 shows the waste eggshell source from Poultry - Dutch Meat & Feed Centre - DMFC Dutch Meat & Feed Centre – DMFC. This shows that soil pollution was created from the waste eggshell¹²⁾. These eggshells destroy a large portion of land¹³⁾. Due to utilization of waste material in the development of new

composite soil pollution can be reduced¹⁴⁾.

Through literature survey, it can be concluded that, very few researchers have used uncarbonized eggshell powder as reinforcement in fabricating the aluminium based composite material by stir casting process using RSM. In this present study, process parameters of stir casting process were optimized by considering hardness as a response factor. The process parameters played a vital role in the development of composite through EMS. Uncarbonized eggshell weight percentage, stirring time, preheat temperature, stirring current and matrix pouring temperature were the selected process parameters. In this research article, the waste uncarbonized eggshell powder was used as reinforcement. The originality of this experiment lie in the fact that only few research has been carried out to utilize waste eggshell for development of new composite material in the archival literature. In this experiment, influence of eggshell power on the hardness of AA 2014/eggshell composite prepared by stir casting method was evaluated.

2. Materials and Methodology

2.1 AA 2014 taken as matrix material

In this experiment, AA 2014 aluminum alloy was taken as matrix material. Nowadays, AA 2014 alloy is used in automotive and aerospace industries due to its superior mechanical properties and light weight. The chemical compositions of AA 2014 alloy are illustrated in Table 1¹⁵⁾. Table 2 demonstrates the mechanical properties of base metal¹⁵⁾.



Fig 1: Waste Eggshell creating soil pollution

Table 1: Configuration of Alloy AA 2014 (wt. %)¹⁵⁾

S. No.	Constituents	Wt.-%
1	Cu	3.89 – 4.99
2	Si	0.49-0.89
3	Fe	0.5
4	Zn	0.25
5	Cr	0.9
6	Ni	0.9
7	Mg	0.2-0.8
8	Ti	0.2
9	Mn	0.4-1.2

Table 2: Mechanical Characteristics of Alloy AA 2014¹⁵⁾

S. No.	Characteristics	Standards
1	Toughness (J/m ⁻³)	about 12
2	Theoretical density (g/cm ³)	2.79
3	Brinell hardness (BHN)	about 60
4	Tensile Strength (MPa)	about 185

2.2 Uncarbonized eggshell as reinforcement

In this study, waste eggshell powder was used as reinforcing content in aluminium alloy. It consist about 94 wt. % of calcium carbonate with some impurities as major composition¹⁶⁾. Waste eggshells collected from city disposal area were cleaned with water. After that eggshells were sundried for 96-122 hours to eliminate the moisture content¹⁷⁾. Eggshells powder was prepared through ball milling process. Ball milled eggshells powder was further pass through multi sieves to obtained desired range of eggshell powder¹⁸⁾.

2.3 Preparation of Composite

EMS technique was used to prepare AA 2014/uncarbonized eggshell composite. Fig 2 shows the layout of stir casting technique. RSM was employed for conduction of experiment. Owing to the uncertainty of experimental results, three samples were papered for each experiment groups. Total numbers of 78 specimens were prepared and the average values of three samples were selected for the analysis of response. Prepared eggshell reinforced aluminium based composite material in mushy zone. Prepared composite was removed after the solidification form mould. Machining of all the samples were carried out for the different testing as per the ASTM standard²⁰⁾. Table No. 3 shows the experimental plan to conduct experiments by EMS process to develop the composite materia

Table 3: Design matrix Table for hardness

Std order	Run	A: Preheat temperature of uncarbonized eggshell powder (°C)	B: Measured electromagnetic stirring current (Ampere)	C: Measured electromag netic stirring time (s)	D: Matrix pouring temperature in crucible after melting in furnace (°C)	E: Uncarbonized eggshell weight percent (%)	Hardness (BHN)
13	1	600	9	120	800	16.6058	87.3
19	2	600	9	120	800	7.5	79.71
9	3	400	6	60	700	2.5	69.3
18	4	600	9	229.2696	800	7.5	81.96
16	5	400	12	60	900	12.5	82.2
11	6	800	6	180	900	2.5	71.4
7	7	800	6	180	700	12.5	85.5
6	8	400	12	180	900	2.5	74.7
8	9	600	9	10.73038	800	7.5	79.14
14	10	800	12	60	700	12.5	85.8
17	11	600	9	120	800	7.5	79.575
26	12	600	9	120	982.116	7.5	76.68
5	13	600	9	120	800	7.5	79.725
3	14	400	12	180	700	12.5	85.5
21	15	600	9	120	800	0	69.39
10	16	600	3.536519	120	800	7.5	79.5
23	17	600	9	120	617.884	7.5	80.25
1	18	800	12	180	700	2.5	74.25
12	19	800	12	60	900	2.5	71.25
25	20	600	9	120	800	7.5	79.62
20	21	800	6	60	900	12.5	82.5
22	22	600	14.46348	120	800	7.5	81
2	23	964.2321	9	120	800	7.5	76.2
4	24	600	9	120	800	7.5	79.68
15	25	400	6	180	900	12.5	83.1
24	26	235.7679	9	120	800	7.5	74.1

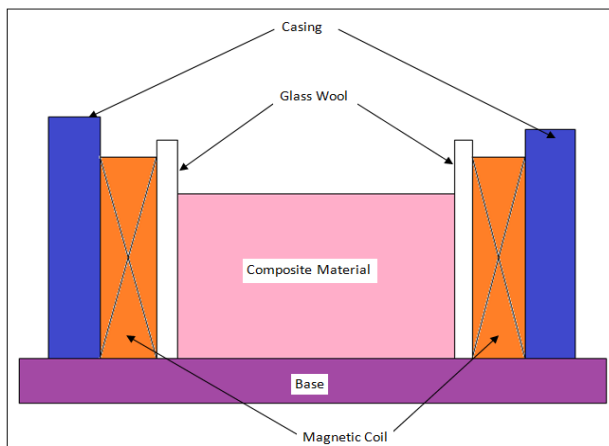


Fig 2: Line diagram of EMS set-up

3. Results and Discussion

Waste material as reinforcement material was utilized in this study¹⁹. Table 3 shows the measured average value of hardness for each experiment groups. Design of experiment (DOE) software was used to conduct the experiment as shown in Table 3. For checking the adequacy of the developed model, F-test was performed. The next subsection will provide the details of the developed model and influence of EMS parameters on hardness.

3.1 Mathematical Modelling for Hardness

A regression model was developed to evaluate the hardness of fabricated composite through the EMS. Table 4 shows the ANOVA of the quadratic regression model and impact of individual EMS parameters. The model F-value of equation 1 was greater than F-tabulated value, which implies that model is statistically correct and can be used for the forecasting of hardness of AA2014/uncarbonized eggshell composite corresponding to given EMS process parameters, within the experimental domain. There is only 0.01% chance for the model to fail due to the uncertainty of results²¹. The probability value (p-value) of all the selected EMS parameters was less than 0.5, which implies that model is fit within the confidence interval of 95²². The value of R² was 0.976355 and Adj R-Squared was 0.999711 closes to each other and also closed to 1. It indicates that the model was significant²³.

$$\begin{aligned} \text{Hardness} = & -1.78294 + 0.10996 \times A + 1.05620 \times B + \\ & 0.10171 \times C + 0.085328 \times D + 0.39226 \times E - 3.44586 \times \\ & 10^{-005} \times A^2 + 0.017707 \times B^2 + 6.93938 \times E^{-005} \times C^2 - \\ & 3.78834 \times 10^{-005} \times D^2 - 0.016601 \times E^2 - 1.47819 \times 10^{-003} \times \\ & A \times B - 1.07235 \times 10^{-004} \times A \times C - 5.16222 \times 10^{-005} \times A \\ & \times D + 2.32718 \times 10^{-004} \times A \times E - 1.65049 \times 10^{-003} \times B \times C - \\ & 3.92376 \times 10^{-004} \times B \times D + 0.021497 \times B \times E - 3.62699 \end{aligned}$$

$$\begin{aligned} & \times 10^{-005} \times C \times D + 3.66805 \times 10^{-004} \times C \times E + 5.78835 \times \\ & 10^{-004} \times D \times E \dots\dots\dots(1) \end{aligned}$$

3.2 Influence of EMS on hardness

Particular EMS process parameters i.e. Uncarbonized eggshell weight percentage, stirring time, stirring current, preheat temperature and matrix pouring temperature have influenced the hardness of uncarbonized reinforced aluminium based composite material. The effects of each EMS parameters on hardness are given below²⁴.

3.2.1 Preheat Temperature Effect on Hardness of Composite

Fig 3 illustrates the influence of uncarbonized eggshell powder preheat temperature on hardness. Results showed that increased eggshell powder content at preheat temperature up-to 600°C had increased the hardness of the composite. However, beyond the 600°C of preheat temperature, hardness began to decrease. Reinforcement preheat temperature shows an important role in the enhancement of hardness. Due to an unwarranted preheating of eggshell powder, results in illusions which results lowering the hardness.

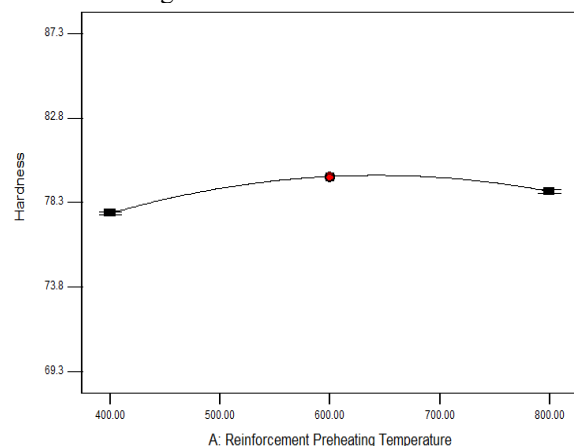


Fig 3: Effect of Preheat Temperature on Hardness of Composite

3.2.2 Stirring Current Effect on Hardness of AA 2014/eggshell Composite

Figure 4 shows the influence of stirring current on the hardness of composite material. Experimental results showed that hardness is continuously increases by increasing the stirring current. Stirring current has inclined the hardness of AA 2014/uncarbonized eggshell composite. It can be observed from Fig. 4 that maximum hardness was achieved at 12 A of stirring current.

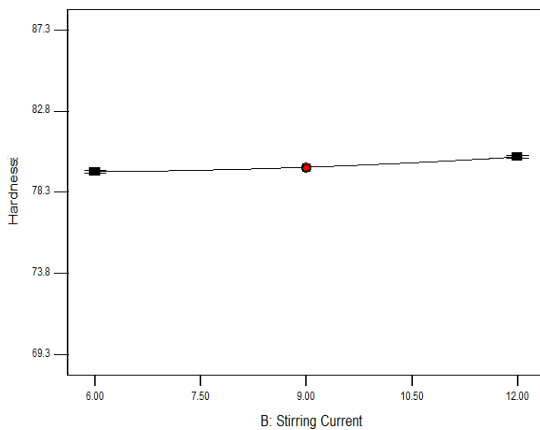


Fig 4: Influence of Stirring Current on Hardness of Composite

3.2.3 Stirring Time Effect on Hardness of AA 2014/eggshell Composite

Graph between stirring time and hardness can be observed from Fig. 5. It was found that hardness was continuously increased by increasing the stirring time of electromagnetic stir casting process. In the selected range of process parameters, it was observed that maximum hardness was achieved at 3 minutes of stirring time.

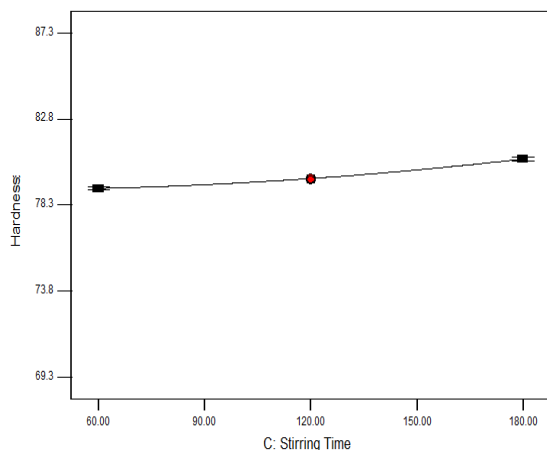


Fig 5: Influence of Stirring Time on Hardness of AA 2014/eggshell Composite.

3.2.4 Influence of Matrix Pouring Temperature on Hardness of AA 2014/eggshell Composite

Fig. 6 shows the effect of matrix pouring temperature on the hardness of composite. Hardness of composite is continuously decreases by increasing the matrix pouring temperature in the selected range of process parameters. Due to the poor interfacial bond between matrix material and reinforcement material hardness decreased at higher matrix pouring temperature. It can be concluded that maximum hardness can be achieved at 700°C (in the selected range of process parameters)

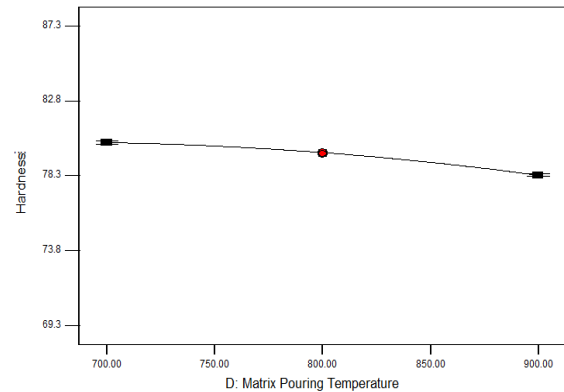


Fig 6: Influence of Matrix Pouring Temperature on Hardness of Composite

3.2.5 Influence of reinforcement of Eggshell Powder weight percent on Hardness of AA 2014/eggshell Composite

Fig. 7 shows the influence of eggshell reinforcement weight percent on the hardness of composite. It can be clearly seen hardness was maximum at 12.5 wt % of uncarbonized eggshell reinforcement. On increase of eggshell wt % hardness was increased. Hardness of composite was increased due to the occurrence of hard phases (CaCO_3) in eggshell powder

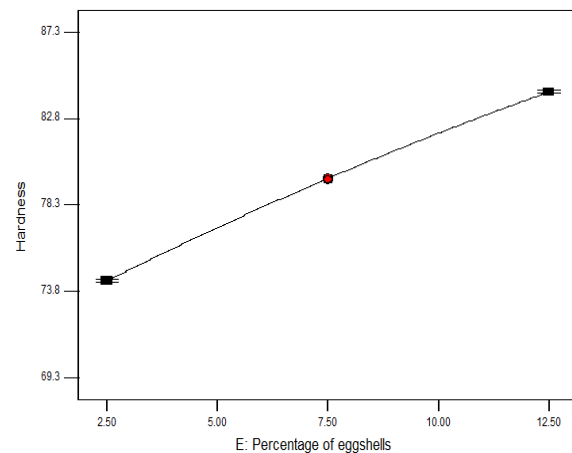


Fig 7: Influence of reinforcement of Eggshell Powder Weight Percent on Hardness of AA 2014/eggshell Composite

3.2.6 3D-Interaction of EMS parameters on Hardness

Fig.8 shows the 3D interaction of EMS parameters on hardness. It can be observed from Figures 8 that, with increasing the reinforcement preheat temperature up to center limit and stirring current, the hardness of composite material also increases. In the same way, interaction effect of others parameters with hardness can be described.

Table 4: ANOVA Table for Hardness Composite

Source	Sum of Squares	DF	Mean Square	F Value	Prob> F	
Model	637.4047	20	31.87024	4328.76	< 0.0001	significant
A	2.205	1	2.205	299.50	< 0.0001	
B	1.125	1	1.125	152.8	< 0.0001	
C	3.9762	1	3.9762	540	< 0.0001	
D	6.37245	1	6.37245	865.5	< 0.0001	
E	160.3841	1	160.3841	21784	< 0.0001	
A2	39.37428	1	39.37428	5348	< 0.0001	
B2	0.526355	1	0.526355	71.50	0.0004	
C2	1.293431	1	1.293431	175.68	< 0.0001	
D2	2.974368	1	2.974368	404	< 0.0001	
E2	3.569646	1	3.569646	484.85	< 0.0001	
AB	2.40404	1	2.40404	326.53	< 0.0001	
AC	5.060749	1	5.060749	687.37	< 0.0001	
AD	3.257707	1	3.257707	442.48	< 0.0001	
AE	0.165515	1	0.165515	22.48	0.0051	
BC	0.269745	1	0.269745	36.64	0.0018	
BD	0.042348	1	0.042348	5.76	0.0618	
BE	0.31776	1	0.31776	43	0.0012	
CD	0.144735	1	0.144735	19.6	0.0068	
CE	0.037008	1	0.037008	5.0	0.0750	
DE	0.255994	1	0.255994	34.7	0.0020	
Residual	0.036812	5	0.007362			
Lack of Fit	0.020882	1	0.020882	5.24	0.08	not significant
Pure Error	0.01593	4	0.003982			
Cor Total	637.4415	25				
Std. Dev.	0.085804712	R ²	0.999942			
Mean	78.82038462	R ² -Adj	0.999711			
C.V.	0.108861067	R ² - Pred	0.976355			
PRESS	15.07205929	Adeq Precision	232.4501			

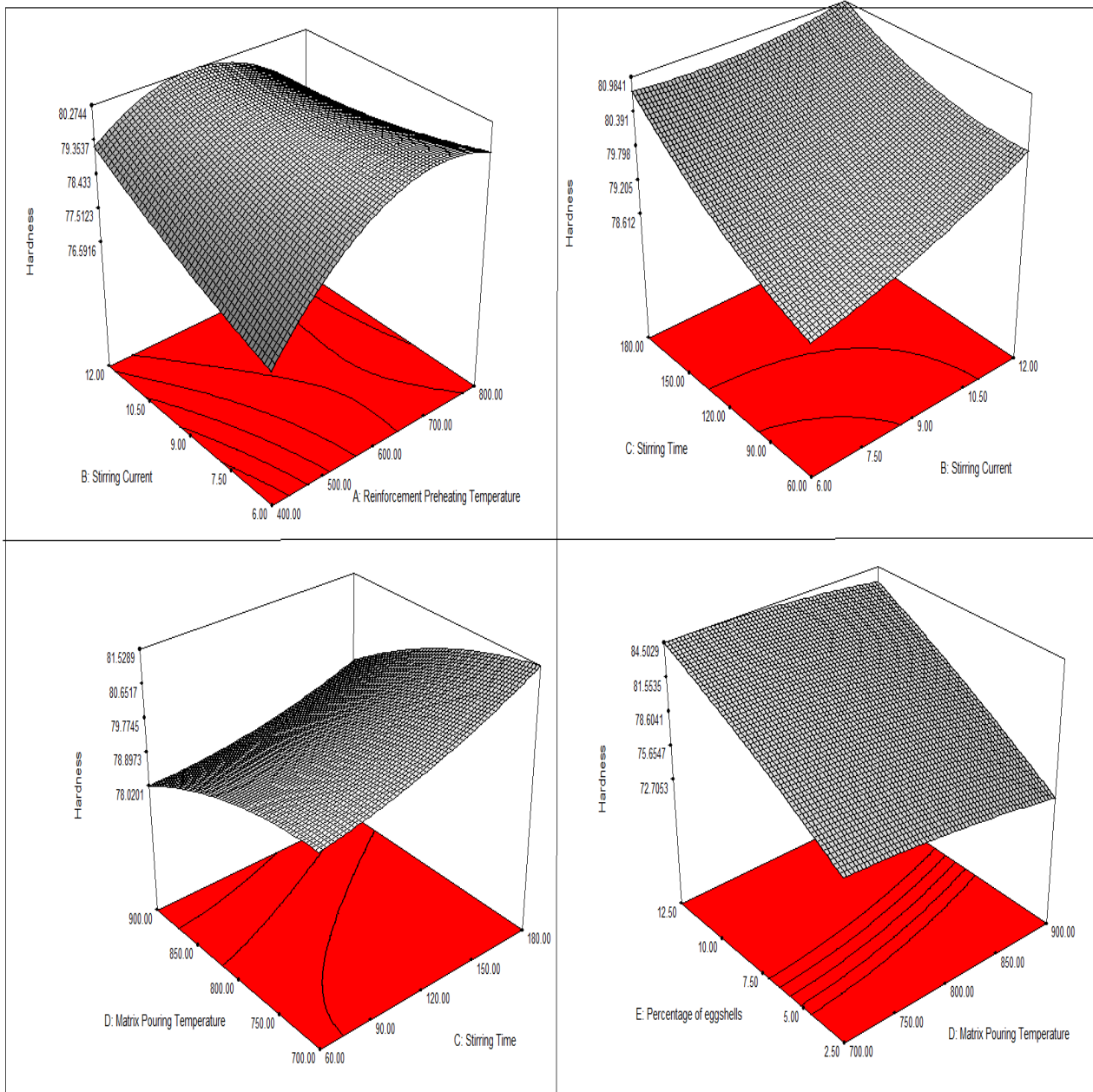


Fig 8: 3D-Interaction of EMS parameters on Hardness

3.3 Confirmation Experiment

A confirmation test was performed to validate the developed regression model. The optimum level of process parameters were found to be stirring current of 12A, matrix pouring temperature of 700°C, reinforcement preheat temperature of 600 °C, stirring time of 3 minutes and reinforcement wt. % of 12.5. Owing to uncertainty of results three samples were fabricated at optimum level of process parameter and average value of hardness of three samples was compared with the model value²⁵⁾. The average value of three samples of hardness was 86.4865 BHN. At the optimum level of process parameter tensile strength was

also evaluated. The average value of tensile strength of three samples was found to be 255 MPa. However, ductility and toughness of composites were reduced as compared to the base matrix material.

Optical Microscopy test was conducted to examine the distribution of eggshells particle in the fabricated composite. Study showed that at optimum level of process parameters uniform distribution of eggshells powder was observed. Fig.10 shows the presence of eggshells in the fabricated composite at optimum level of process parameter.

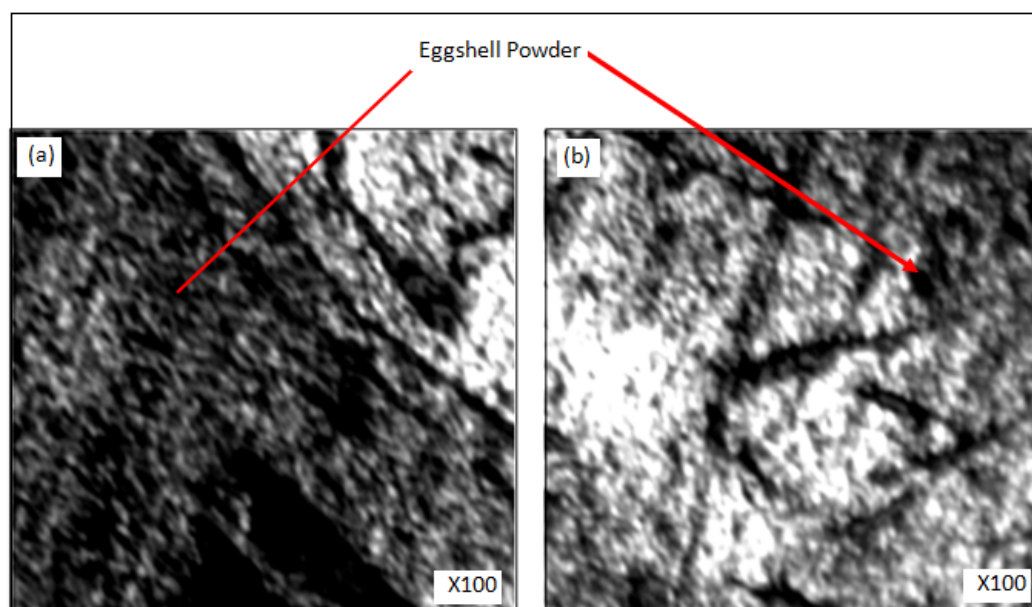


Fig 10: Microstructure of AA2014/12.5 wt. % uncarbonized eggshell composite

3.4. Comparison of result with previous experimental results

Table 5 shows the comparative study of effect of reinforcement of eggshell particles on mechanical properties of aluminium alloys. It was observed that due to reinforcement of eggshell particle mechanical properties tensile strength and hardness were improved. However, other mechanical properties i.e. toughness and ductility were decreased. Dwivedi et.al¹⁵⁾ have conducted experiment to find out optimum electromagnetic stir casting process parameter for response factor tensile strength and conducted other mechanical properties at corresponding optimum level of process parameters. The optimum level of process parameters are shown in Table 5. In this study, effect of reinforcement of uncarbonized eggshell on mechanical properties of AA2014 was investigated. Mechanical properties hardness was selected as a response variable. At optimum level of process parameters tensile strength was also calculated. Dwivedi et.al¹⁵⁾ results showed that tensile strength was improved at optimum electromagnetic stir casting parameter about 51.35% with respect to base alloy, when tensile strength was considered as response. However, hardness was also increased about 41.66%.

In the present study, hardness was improved about 44.73% with respect to base alloy at optimum EMS process parameters when hardness was considered as response. Tensile strength at corresponding EMS process parameters was increased about 37.83%. From these results, it can be concluded that the optimum level of process parameters for tensile strength and hardness were different as shown in Table 5. Sometimes, tensile strength is more important factor in the selection of material. In

this case, composite material should be developed at the optimum combination of EMS process parameters by considering tensile strength as response. In certain applications, where relative motion between surfaces of the components exists due to which wear and tear occur. To minimize surface wear, hard materials are required without significant changes in tensile strength of material. Keeping these facts in the mind, in this study, hardness was considered as response. For AA2014/eggshell composite can be forecasted by using the suggested regression model (equation 1).

Hassan et al.⁷⁾ has conducted experimental study to investigate the effect of carbonized eggshell as reinforcement on tensile strength and hardness of Al-Cu-Mg alloy. Stir casting technique was used to develop the eggshell reinforced Al-Cu-Mg alloy based composite. Results revealed that tensile strength and hardness of Al-Cu-Mg/12 wt. % eggshell were improved about 14.28 % and 25.4 % respectively.

Current study was performed on electromagnetic stir casting (EMS) set-up. In this set-up, composite material is mixed by using the magnetic forces developed by electromagnetic field. There is no any stirrer is used to mixed the materials, Hence, probability of porosity occurrence is very low. While, in mechanical stir casting process, external stirrer is used to mix the reinforcement particles in the melted matrix material. In this case, probability of porosity occurrence is very high. Resulting, mechanical properties of composite developed by stir casting process are low as compared to electromagnetic stir casting (EMS).

Table 5: Comparing Properties of Present Investigation with the Previous Work

S.N	Author Name	Base Material	Reinforcement particle	Optimum process parameters	Response variable	Mechanical Properties of composite		Percentage change
1	Present study	AA2014	Un-carbonized Eggshell	SC = 12A, MPT=700°C, RPT = 600 °C, ST= 180 s RWT = 12.5 (Electromagnetic stir casting)	Hardness	Tensile strength	255 MPa	37.83 % Increased
						Hardness	86.84 BHN	44.73 % Increased
2	Dwivedi et.al ¹⁵⁾	AA2014	Un-carbonized Eggshell	SC = 12A, MPT=764.96°C, RPT = 608.28 °C, ST= 178.38 s RWT = 12.5 (Electromagnetic stir casting)	Tensile strength	Tensile strength	280MPa	51.35% increased
						Hardness	85BHN	41.66% Increased
						Toughness	Joule	20.83% decreased
						Ductility	% Elongation	9.09% decreased
3	Hassan et al. ⁷⁾	Al–Cu–Mg alloy (Tensile Strength =98.28 MPa, Hardness = 59.12 HRF)	Carbonized eggshell	ST= 900 s RWT = 12	-	Tensile strength	112.84 MPa	14.28 % Increased
						Hardness	74.17 HRF	25.4 % Increased

4. Conclusions

In this study, AA 2014/eggshell based composite material was effectively prepared by using uncarbonized eggshell powder as reinforcement content via EMS. EMS parameters were optimized by considering hardness as response. Optimum process parameters of EMS was found to be stirring current of 12A, matrix pouring temperature of 700°C, reinforcement preheat temperature of 600 °C, stir time of 3 minutes and reinforcement weight percentage of 12.5. Hardness and tensile strength of AA 2014/eggshell composite was observed at optimum reinforcement parameters. Hardness and tensile strength were enhanced by 33%, 37.83 % respectively as compared to base metal.

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