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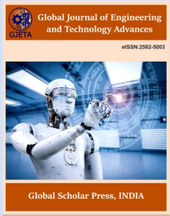

(RESEARCH ARTICLE)

Effect of green sand mixture with dextrin additives on mechanical properties of aluminum 6351

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Abstract

Quality of cast produced from green sand mold is been influenced by mold properties which includes green compression strength, permeability, etc. In this work the green sand used for casting of aluminum 6351 alloy specimens were made by mixing in varied percentage proportions; bentonite clay, dextrin additive and moisture content with local silica sand considering the need for most effective proportions of these mixtures to enhance green sand production of aluminum 6351 alloy products. A 3 factor, 3 level (33) design of experiment (DOE) was made for this research work using Optimal (custom) design of Design-Expert 10 software which gave 20 runs. Cylindrical specimens for green sand test were prepared according to standard per run. This was in order to study effects of bentonite clay, dextrin additive and moisture content of the green molding sand used for casting per mold this aluminum 6351 alloy. Prepared sand specimens were individually subjected to basic sand test like green sand strength and permeability test and also cast specimens per mold achieved were subjected to mechanical property test to achieve results which become the Response output of the study. These experimental results were optimized for the purpose of achieving most effective proportions of the mixtures to give effective results and from the optimal validation values, 5% water content, 12% bentonite and 8.85182% dextrin organic additive was found to be the optimized solution that gave the most effective hardness at (40.4GSS and 112PN) while 3% water, 12% bentonite clay and 9% dextrin additive gave most effective toughness at (41.9GSS and 96.10PN).

Keywords: Dextrin; Green sand strength; Permeability; Hardness; Toughness

1 Introduction

The desire to produce lightweight, parts with near net shape in industry has become highly researchable topics [1]. Casting as of today is one of the most important manufacturing process widely in used. Casting is used for making intricate shapes which are difficult or too expensive to make by other methods. Casting process is vast and is carried out on almost all metals. Aluminum alloys are widely used for hundreds of compositions by all commercial casting processes including green sand, dry sand, composite mold, plaster mold, investment casting, permanent mold, etc. Aluminum alloys have excellent mechanical properties which include high strength, low density, durability, machinability and others required in manufacturing industries. These alloys are used in advanced applications due to their combinations, availability and relatively low cost as compare to competing materials. There are many process parameters affecting properties of final casted product but the additives presents in sand significantly impact final casted products. Additives are added to molding components to improve surface finish, dry strength, refractoriness, and cushioning properties [2]. Recently, additives are gaining greater application in sand mold preparation. Apart from intrinsic properties of molten metal such as fluidity, composition, segregation, etc., which affects the soundness of the cast produced, mold properties also play prominent role in determining the soundness of a casting. Other factors that may affect the heat storage capacity of sand mold includes; composition of mold material, the moisture content and

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mold temperature. Sand casting accompanying advantage over others includes; wide range of castable sizes, flexibility to mechanization, ease of handling and cost effectiveness [3, 4]. The principal constituents of molding sands are; sand grains, clay (binder), moisture and organic additives. Virtually all sand cast molds for Aluminum casting are these days green sand type mostly [5]. Green sand consists of high-quality silica sand, about 10 to 20 percent bentonite clay, 2 to 5 percent water and certain percentage of organic additive. Good molding sand always represent a compromise between conflicting factors and to obtain an acceptable compromise for the four basic requirements, the size of the sand particles, amount of bonding agent (clay), the moisture content, and organic matter percentage are all selected [6]. When molding sands are used for mold making without additives, some important characteristics may be absent in the molding sand [7]. When additives are added to molding sand, certain properties including high plasticity, temperature, metal penetration property and surface finish are improved [5]. Additives are mixed during sand preparation according to the requirement of molten metal and base sand to obtain specific characteristics in sand [6]. This study used statistical approach to check the effect of green sand mixtures with dextrin as organic additive, on mechanical properties of Aluminum 6351 alloy.

2 Material and Methodology

2.1 Material

The materials used for this research work were Aluminum (Al), Silicon powder (Si), Magnesium powder (Mg), Manganese powder (Mn), Corn flour, Dextrin powder, Bentonite clay, local Silica sand, water, wooden mold, Thermometer, Aluminum foil, Slag stick, Furnace, large metallic and plastic containers, Analogue and Electronic Scales, trowel and other casting components. They were locally sourced.

2.2 Methodology

Optimal (custom) DOE of Design Expert software was applied in this study to assess the influence of process parameters on quality of castings. The number of runs and design matrix depends on the number of factors and their levels. Here, number of factor is ‘three’ and number of levels ‘three’ (3^3) as shown in Table 2.0. Also table 1 shows its design matrix.

Table 1 Independent Variables and experimental design levels.

	Name	**Units**	**Type**	**Levels**	**L[1]**	**L[2]**	**L[3]**
A[Numeric]	Water	%	Discrete	3	3	4	5
B[Numeric]	Bentonite	%	Discrete	3	10	11	12
C[Numeric]	Dextrin	%	Discrete	3	7	8	9

Table 2 Design Matrix

Run	**Factor 1 A:Water %**	**Factor 2 B:Bentonite %**	**Factor 3 C:Dextrin %**	**Response 1 Green sand strength KN/M^2**	**Response 2 Permeability PN**	**Response 3 Hardness test BHN**	**Response 4 Impact test Joules**
1	3	10	7				
2	5	10	9				
3	3	11	8				
4	3	12	7				
5	4	11	9				
6	5	12	8				
7	4	12	7				
8	5	12	8				
9	3	12	9				

10	4	10	8				
11	5	12	7				
12	4	11	8				
13	5	11	7				
14	3	10	9				
15	5	10	9				
16	5	12	9				
17	3	11	7				
18	5	11	7				
19	3	11	8				
20	4	11	9				

2.2.1 Molding Mixture

Molding mixtures used for this green sand casting experiments were silica sand, bentonite clay, dextrin additive and water content. The silica sand used was first sieved through a 2mm mesh size to remove coarser particles than the finer grain sizes before sieve analysis. The samples were vibrated continuously for 15minutes by the use of sieve shaker having mesh sizes which ranged from 1.44mm to 45micron meter with a lid above and cover pan below them. The sieve sizes used for the experiment were classified according to the following mesh number shown in Table 3.

Table 3 Grain fineness number for sand sample (AFS).

Mesh sizes	Weight of sand on mesh (g)	Multiplier	Product	Cumulative retained sand
1.44mm	6.0	10	60	60
710μm	7.920	16	126.72	186.72
500μm	9.350	22	205.70	392.42
355μm	11.880	30	356.40	748.82
250μm	13.860	44	609.84	1358.66
125μm	15.010	85	1275.85	2634.51
90μm	17.880	120	2145.60	4780.11
45μm	14.012	240	3362.88	8142.99
Cover pan	4.080	350	1428.00	9570.99
Total	99.992			9570.99

GFI: Grain fineness Index
GFI = 9570.99/99.992 ≈ 96

Each green sand mixture was achieved using laboratory size Muller (mixer) made by Ridsdale and Co. Ltd. with serial No.845. For each batch the mixing was up to 5 minutes before it was discharged. Bentonite clay, Dextrin additive and water content were varied according to the above DOE matrix runs in Table 2. The portions taken out from each prepared sand mixture was used to prepare standard test specimen (5cm x 5cm) by the use of specimen cylindrical tube, a digital weighing balance and sand rammer.

2.2.2 Green Permeability (GPN) and Green compression strength (GCS)

5cm x 5cm in diameter and height test piece for each was prepared for green compression and permeability test using Ridsdale-Dietert Metric Standard Rammer. A test piece specimen of 5cm x 5cm in diameter and height according to bentonite clay, dextrin additive and water percentage ratios mixed with silica sand per run was prepared using test cylindrical tube, digital weighing balance and Ridsdale rammer. After this the specimen was carefully stripped and removed from the tube for test using strip block. Then the 5cm x 5cm green sand mixture was transferred to Universal Strength testing machine. Versatile equipment pvt. Ltd was used for determing Green Compression strength (GCS). For the test permeability, after the same procedure used for producing 5cm x 5cm test piece was concluded, this time the test piece was not stripped out from the cylindrical tube, rather was taken while inside the tube to Ridsdale and Co. Ltd with serial No. 872 for permeability test.

Permeability number 'N' is volume of air (in cm^3) passing through a sand specimen of $1cm^2$ cross-sectional area and 1cm height, at a pressure difference of $1gm/cm^2$ in one minute.

N = VH/ATP
Where, N = permeability number
V = volume of air passing through the specimen in c. c.
H = height of specimen in cm
P = pressure of air in gm/cm2
A = cross-sectional area of the specimen in cm2
T = time in minutes.

3 Results and discussion

Table below shows the results gotten from the test conducted according to design matrix runs in chapter three.

Table 4 Design Matrix with experimental results.

Run	Factor 1 A:Water %	Factor 2 B:Bentonite %	Factor 3 C:Dextrin %	Response 1 Green sand strength (KN/M^2)	Response 2 Permeability (PN)	Response 3 Hardness test (BHN)	Response 4 Impact test (Joules)
1	3	10	7	57	86.46	75	3.3
2	5	10	9	50.89	102.47	92	4.3
3	3	11	8	50.24	94.66	72	4
4	3	12	7	44.3	99.2	80	6.8
5	4	11	9	47.21	103.5	83	4.2
6	5	12	8	44.8	110.36	91	5
7	4	12	7	48.65	97.86	80.5	4
8	5	12	8	45	111.42	89	5.4
9	3	12	9	43.5	99	79	7
10	4	10	8	56.64	86.96	77	3.8
11	5	12	7	44.2	108	89	5
12	4	11	8	49.1	98.95	88	6
13	5	11	7	52.7	101.8	84	4.5
14	3	10	9	58.9	94.82	74.2	3.7
15	5	10	9	53.76	106	87	3
16	5	12	9	41.5	115.87	93.4	5
17	3	11	7	50.65	96.84	75	4.7
18	5	11	7	52.01	99.05	85	4.4
19	3	11	8	51.05	93.98	73	4
20	4	11	9	47.32	105.2	84	4.2

The control sample for this study are shown in table 5 below.

Table 5 Mechanical properties of as cast composite (control sample)

S/n	Green sand strength (GSS)	Permeability (PN)	Hardness (BHN)	Impact Joules
1	70	93	92	5
2	64	85	90	7
Average	67	89	91	6

The Tables (6-9) below shows ANOVA results for required models of the experiment. ANOVA is the analytical technique used to identify the importance of model(s) and its parameter(s) using student t test and fishers f test [8]. Determining of the significance of regression coefficient was done by Student's t test using P value standard. Generally, smaller p value and F value indicates more significant coefficient terms [9].

Tables 6, 7, 8, and 9 showed ANOVA results for green strength, permeability, hardness and impact response respectively. Also, same tables showed other adequacy measures which are 'R-square', 'adjusted R-square' and 'predicted R-square'. All these adequacies measured were in agreement logically and as well indicate significant relationships. These tables showed also statistical summaries of each model that was the output by Design Expert 10. 2FI (two factorial interaction), quadratic, linear and linear models were suggested even though they have lower adjusted 'R-square' (Adj-R^2) values than cubic models. The reason is because cubic model is aliased, which means the effects of each variable causing different signals became indistinguishable.

Coefficient of determination of 'R-square' is defined as the ratio of explained variation to total variation, and it is the measure of degree of fit. A good model fit should yield 'R-square' of not less than 0.8 [10]. Also 'R-square' value less than 0.8 is also good when 'Pred R-square' is in reasonable agreement with 'Adj R-square'. That is when their difference is less than 0.2.

Adequate precision (Adeq Precision) measures signal to the noise ratio. And any ratio greater than 4 is desirably good. These four models have adequate precisions that are greater than 4 which indicated adequate signals. These models can be used to navigate design space.

The hardness model F-value of 30.61 from table 10 implies that the model is significant. There are only 0.01% chances that an F-value this large could actually occur due to noise. This F-value lower than 0.05 indicated that model terms are significant. In this model, bentonite clay, dextrin additive and water content are significant factors affecting hardness response on the cast product. Water with P value of 0.0001 indicates the most effective on hardness response.

Analysis for variance result for Hardness model showed that the main effect of these mixtures in varied percentage proportion along with three interactive effects are significant model terms. However, water has the most effect on the hardness response with dextrin having the least effect as evident in the results obtained for F value (Fisher Tests). Table 7 for the permeability model, indicated that main effect of the three variables factors and the interactive effect of parameters are significant in the order AB, AC and BC. Bentonite clay has the most significant effect on the permeability with the highest F value of 135.46 followed by water that has F value of 104.66 and dextrin having the least significance of 79.94 F value.

Table 9 showed ANOVA analysis for impact response model with main effect of the process and the interactive effects being significant here. Model F value is 5.90 and it implies significance of model. Bentonite with F value of 17.28 indicates this factor as most significant followed by water that has 1.31 F value and dextrin as the least with F value of 0.40.

The ANOVA analysis for green sand strength response model shown in Table 6 gave model F value of 30.61 with main effect of the process with also interactive being significant in its case. The model F value is 30.61 and it implies significant. Also there is only 0.01% chance that an F-value this much could occur due to noise. The least F value is 3.24 which showed water as the factor having the least effect while bentonite with 160.35 F value is the factor with most effective significant.

Table 6 ANOVA analysis for Green sand strength model

Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	415.41	6	69.23	30.61	< 0.0001	Significant
A-Water	7.32	1	7.32	3.24	0.0952	
B-Bentonite	362.72	1	362.72	160.35	< 0.0001	
C-Dextrin	25.83	1	25.83	11.42	0.0049	
AB	5.26	1	5.26	2.32	0.1513	
AC	13.82	1	13.82	6.11	0.0280	
BC	1.69	1	1.69	0.75	0.4035	
Residual	29.41	13	2.26			
Lack of Fit	24.70	8	3.09	3.28	0.1034	not significant
Pure Error	4.71	5	0.94			
Cor Total	444.81	19				

Std. Dev.	1.50	R-Squared	0.9339
Mean	49.47	Adj R-Squared	0.9034
C.V. %	3.04	Pred R-Squared	0.7983
PRESS	89.71	Adeq Precision	18.791

Table 7 ANOVA analysis for Permeability model

Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	Squares	df	Square	Value	Prob > F	
Model	1065.40	9	118.38	41.80	< 0.0001	Significant
A-Water	296.36	1	296.36	104.66	< 0.0001	
B-Bentonite	383.60	1	383.60	135.46	< 0.0001	
C-Dextrin	226.37	1	226.37	79.94	< 0.0001	
AB	35.74	1	35.74	12.62	0.0052	
AC	51.82	1	51.82	18.30	0.0016	
BC	27.46	1	27.46	9.70	0.0110	
A^2	34.57	1	34.57	12.21	0.0058	
B^2	46.26	1	46.26	16.34	0.0024	
C^2	19.75	1	19.75	6.97	0.0247	
Residual	28.32	10	2.83			
Lack of Fit	16.07	5	3.21	1.31	0.3866	not significant
Pure Error	12.25	5	2.45			
Cor Total	1093.72	19				

Std. Dev.	1.68	R-Squared	0.9741
Mean	100.62	Adj R-Squared	0.9508
C.V. %	1.67	Pred R-Squared	0.8719
PRESS	140.08	Adeq Precision	26.039

Table 8 ANOVA analysis for Hardness model

Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	734.02	3	244.67	30.61	< 0.0001	significant
A-Water	571.45	1	571.45	71.50	< 0.0001	
B-Bentonite	48.05	1	48.05	6.01	0.0261	
C-Dextrin	38.87	1	38.87	4.86	0.0424	
Residual	127.87	16	7.99			
Lack of Fit	111.87	11	10.17	3.18	0.1060	not significant
Pure Error	16.00	5	3.20			
Cor Total	861.89	19				

Std. Dev.	2.83	R-Squared	0.8516
Mean	82.56	Adj R-Squared	0.8238
C.V. %	3.42	Pred R-Squared	0.7784
PRESS	190.97	Adeq Precision	15.993

Table 9 ANOVA analysis for Impact model

Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	10.99	3	3.66	5.90	0.0066	Significant
A-Water	0.81	1	0.81	1.31	0.2696	
B-Bentonite	10.73	1	10.73	17.28	0.0007	
C-Dextrin	0.25	1	0.25	0.40	0.5380	
Residual	9.94	16	0.62			
Lack of Fit	9.01	11	0.82	4.40	0.0571	not significant
Pure Error	0.93	5	0.19			
Cor Total	20.93	19				

Std. Dev.	0.79	R-Squared	0.5251
Mean	4.62	Adj R-Squared	0.4360
C.V. %	17.08	Pred R-Squared	0.2548
PRESS	15.59	Adeq Precision	6.985

4 Effect of Process Parameter on Responses

Optimization

The table 10 below showed the optimization criteria used in this study for the purpose of obtaining optimal solutions of these response outputs.

Table 10 Optimization criteria used in this study.

	Factors and Responses	Limits		Criterion	Goal
		Lower	Upper		
Factors	Water	3	5	In range	In range
	Bentonite clay	10	12	In range	In range
	Dextrin additive	7	9	In range	In range
Responses	Green sand strength	41.5	58.9	In range	In Range
	Permeability	86.46	115.87	In range	In Range
	Hardness	72	93.4	In range	Maximize
	Impact (toughness)	3	7	In range	Maximize

Below optimal solution values obtained by Design expert base on the maximizing criterion of each Response surface output showed variation in mechanical properties of aluminum 6351 alloy. From these results analysis, it is clearly seen that increase in the percentage proportion of water from 3% to 5% increasingly effected hardness and also increase in bentonite clay increasingly effected toughness and respectively they stand as the most effective to these response outputs. From Design expert's analysis, Dextrin organic additive showed its most effect on the hardness property when its proportion neared 8.5% to 8.84% and also on toughness when its proportion neared 8.99% to 9%. This is mostly at a certain proportions of the other mixtures. These input factors in their various proportions showed effect on the mechanical properties of this aluminum 6351 alloy and at this level, there is need to validate the experimental results for an effective green sand casting.

Table 11 Optimal solution as obtained by Design Expert based on the criterion and Goal on green sand strength (GSS).

Number	**Water**	**Bentonite clay**	**Dextrin additive**	**Green sand strength**	**Permeability**	**Hardness**	**Impact (toughness)**	**Desirability**
1	3	10	9	57.727	94.5383	75.3677	3.9072	0.933
2	3.0088	10	8.99997	57.7029	94.5248	75.423	3.90513	0.931
3	3.00001	10	8.84785	57.6966	93.2615	75.1055	3.88635	0.931

Table 12 Optimal solution as obtained by Design Expert based on the criterion and Goal on Permeability (PN)

Number	Water	Bentonite clay	Dextrin additive	Green sand strength	Permeability	Hardness	Impact (toughness)	Desirability
1	4.98396	11.6954	8.94161	42.9183	116.258	91.298	5.11479	1.000
2	4.9683	11.8379	8.97527	42.0342	116.481	91.5574	5.26481	1.000
3	4.98991	11.9442	8.91936	41.5799	116.302	91.8205	5.35774	1.000

Table 13 Optimal solution as obtained by Design Expert based on the criterion and Goal on hardness (BHN)

Number	Water	Bentonite clay	Dextrin additive	Green sand strength	Permeability	Hardness	Impact (toughness)	Desirability
1	5	11.9923	8.85488	41.5	115.87	91.8738	5.39425	0.929
2	5	11.9972	8.84599	41.5001	115.79	91.8689	5.39794	0.928
3	4.99999	11.9845	8.85459	41.5441	115.87	91.857	5.3865	0.928

Table 14 Optimal solution as obtained by Design Expert based on the criterion and Goal on impact (toughness).

Number	Water	Bentonite clay	Dextrin additive	Green sand strength	Permeability	Hardness	Impact (toughness)	Desirability
1	3	12	9	43.2099	98.5253	79.5751	5.89556	0.724
2	3.00895	11.9999	8.99998	43.2006	98.5517	79.6311	5.89336	0.723
3	3.01845	12	8.99966	43.1898	98.5781	79.6904	5.89115	0.723

5 Validation of Test

Table 15 Validation of test

Exp. No	Water	Bentonite	Dextrin		Green sand strength (GSS)	Permeability (PN)	Hardness (BHN)	Impact (toughness) Joules
1	3.00293	10	8.94927	Actual	55.5	91.70	72	3.1
				Predicted	57.7088	94.1082	75.2987	3.89956
2	4.98012	11.84250	8.94541	Actual	40.8	114.30	87	4.1
				Predicted	42.1775	116.347	91.5586	5.24578
3	4.99999	11.99133	8.85182	Actual	40.4	112.00	89	4.4
				Predicted	41.5147	115.8433	91.86657	5.39897
4	3.00913	11.99997	8.99988	Actual	41.9	96.10	75	4.7
				Predicted	43.2001	98.5517	79.6322	5.8934

Due to the effect of various proportions of water content, bentonite clay and dextrin additives mixed with silica sand to the permeability and green strength of this molding sand, variation in white patches of the solid solution of these alloy casts are seen in their microstructure. Permeability is actually the passage of gas through the sand. This ability of air to pass through sand grains is effected by the percentage proportions of the mixtures in the molding sand. These mixture contents therefore affects the temperature of casting and rate of cooling which consequently affects solidification process, type of grain and the microstructure formed. In order to achieve mechanical properties in its optimal form, it is very essential for these alloying elements to be uniformly distributed. This simply means that right measures and proportions of these green sand mixtures are needed for effective green sand casting of aluminum 6351 alloy.

6 Conclusion

The following conclusions were drawn from the research work.

- Green molding sand mixtures which contains water (3% - 5%) bentonite clay (10% - 12%) and dextrin organic additive (7% - 9%) were varied successfully.
- Though the whole green sand mixture contents had effects in the properties of the cast, moisture content within its chosen variations has the most effect on the hardness property.
- Green sand mixture content at (water 5%, bentonite clay 12% and dextrin organic additive 8.85182%) gave the highest hardness of 89 BHN from the optimal values.
- Bentonite clay factor had most effect on toughness response output, when set at (water 3%, bentonite clay 12% and dextrin organic additive 9%) gave 4.7 joules as the highest toughness value from the validation test.
- Dextrin organic additive with its dependant nature to other mixtures showed most effect on hardness and toughness when between 8.8% and 9%. This means, the dextrin organic additive used in this study when mixed with other mixture contents at; (water 5%, bentonite clay 12% and dextrin organic additive 8.85182%), gave most effective hardness and when at (water 3 %, bentonite clay 12% and dextrin additive 9%), gave most effective toughness.
- In comparison of as cast aluminum 6351 mechanical properties with properties from aluminum cast using optimized factors results has a percentage deviation of 20.72% Gss, 28.09% PN, 2.25% hardness and 27.66% toughness.

This research work gives understanding to the effect of green sand mixtures with dextrin as organic additive to mechanical properties of Aluminum 6351 alloy. Optimized parametric values of water content, bentonite clay and dextrin organic additive were obtained using statistical method. Also, enhance mechanical properties from optimized calculated values of factors gave resulted enhanced Aluminum 6351 alloy.

Compliance with ethical standards

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Disclosure of conflict of interest

There are no conflict of interest for this research.

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