Experimental Study of Optimization of Dry Compressive Strength of Groundnut Shell Ash and Ant Hill Powder-Bonded Sand for Foundry Application

Patrick C. Okonji, Chidozie C. Nwobi-Okoye, Kennedy C. Owuama

Abstract- **The optimization of dry compressive strength of groundnut shell ash (GSAp) and ant hill powder (AHp) was investigated. Ratio of: 2/0, 4/5, 6/10, 8/15, 10/20, 12/25, 14/30% GSAp/AHp was used in the formulation. Taguchi method was used to determine the optimization condition. The work shows that the maximum baked compressive strength of 356.7, 355.0, 335.3 kN/m^2 was obtained at 5, 2, 1h and 100, 200, 300^{o}C at 14/30% GSAp/AHp addition. GSAp/AHp has the greatest effect (97.61%), followed by time (2.03%) and the least temperature (0.35%). The shear strength of 78.12, 110.00, 123.00, 145.60, 154.67, 158.90 and 168.9 kN/m^2 were obtained at 2/0, 4/5, 6/10, 8/15, 10/20, 12/25, 14/30% GSAp/AHp respectively. The optimal condition for the dry compressive strength for the selected factors and levels was achieved at GSAp/AHp level L3, time L2 and temperature L1. At optimum quantities of GSAp (14%) and AHp (30%) added to silica sand, the results obtained showed that groundnut shell ash and ant hill powder-bonded sand can be suitable for use in the foundry industry for preparation of moulds and cores.**

Index Terms- **Taguchi, Groundnut shell, Ant hill, Dry compressive strength**

I. Introduction

Silica sand is one of the major materials used in the foundry industry worldwide. It is used in making the mould and creation of the internal cavity in the mould for the casting of internal shapes [1]. Binders are usually added to sand to hold the grains together, form a strong bond and an enhanced strength [2-3]. Silica sand is found in nature on the bottoms and banks of river, lakes, on seashores, in dry river deposits, and in substrata layers of the earth. Groundnut, generally known as peanut, is one of the world's principal oil seed crops. Groundnut shell ash material is a waste bye-product produced during the burning of groundnut shell after milling of the groundnut and present a serious ecological problem associated with their storage and disposal, [4]. An ant-hill, in its simplest form, is a pile of earth, sand, pine needles, or clay or a composite of these and other materials that build up at the entrances of the subterranean dwellings of ant colonies.

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Binders for core and mould making could be organic or inorganic [5]. The common binders used in the foundry industry today are expensive and, therefore, results in an increase in the cost of the final product. However, the use of local materials as a binder for core and mould making has not been totally exhausted despite the economic loss to importation [6]. Biomass waste (such as sawdust, rice husk, palm kernel shell, groundnut shell, sugarcane bagasse) has found its way as one of the favourable means of creating a cleaner environment, waste recycling to valuable products, [7]. Research has shown that fly ash and biomass ash materials have many of the same attributes of foundry sand. These ashes have a very high melting point, can absorb and transmit heat during pouring and have the ability to allow gases to pass through a compacted mass, [4]. Therefore, the development of suitable scientific, technical and economic solutions for the use of groundnut shell and ant hill is very desirable and important.

II Review Of Related Research Findings

Numerous factors such as time, temperature, particle size, moisture content, mouldability, compactibility affect the properties of foundry sands in metal casting [5-6]. In order to have a casting free from defects, as well as to develop cost effective and ecofriendly materials there has been an increase in research efforts: Jakubski et al [8] reported on optimization of foundry sand. The neural network was used to determine the properties of bentonite bonded sand. Priyadharsini et al [9] reported on the local binder named Ipomoea batatas gum and bentonite addition to silica sand. Their results showed good properties when combining Bentonite and Ipomoea batatas as a binder. Ihom and Offiong [10] studied the optimization of the dry compressive and shear strength of Ashaka clay and sand using regression method. Their results show that there is a linear relationship between the parameters in their work. Stachowicz et al [11] reported on the effect of water glass on the hardening ability of silica sand. Moulding sands with addition of 2.5 % of binder with molar module 2.0 were hardened with CO_2 and dried in traditional way or hardened with microwaves. Their results proved that the hardening method affects structure of bonding bridges, correlating with properties of the hardened moulding sands. Investigation was carried out on the prospect of local core binders in foundry industries, Onuegbu et al [4]. This research established that if the locally available oils such as vegetable oils, soya beans, cotton-seed, groundnuts, palm-kernel, benin-seed, cashew nuts, castor oils and cassava starch are properly developed and improved upon, they are cost effective and more environmental friendly compared with some foreign ones.

The effect of high alumina cement on some selected foundry properties of ant-hill clay has been investigated, Akinwekomi et al [12]. The chemical analysis of the ant-hill clay used in the research showed silica content of 55.89% and alumina content of 23.61%. This high percentage of alumina in the ant hill means that the ant hill can be classified under siliceous fireclay. The result further showed that the ant hill belongs to the fireclay accepted standard and falls within the range of semi-plastic binding clays. Investigation of the efficacy of moisture content and the bonding capacity of the River Niger Onitsha (in Nigeria) beach sand was carried out by Agbo et al [13]. Mechanical properties tested included green and dry compressive strengths, dry shear strength, and permeability. The results obtained showed that green compressive strength was 21.69kN/m^2, dry compressive strength was 210kN/m^2, permeability was 150.50 No. The results compared favourably with those obtained with bentonite. Ukpor clay could serve as a satisfactory alternative to bentonite for use as binding clay, in nonferrous foundry. Nuhu et al [14] reported on use of oil extracted from Nigerian variety of water melon seed as sole binder for foundry sand cores. Permeability and compressive strength tests were carried out on freshly moulded specimens. Results showed that cores with compositional mix of 1-3% water melon seed oil had adequate foundry characteristics for production of classes II-V iron and steel castings. Cores bonded with the oil were unsuitable for classes I and II iron/steel and nonferrous castings.

Based on the foregoing and other literature findings it appears that the use of GSAp and AHp has not been given much attention in foundry application. The need to determine the relationship between the compressive strength of GSAp, AHp and silica sand is the main thrust of this present work.

III. Experimental Procedure

A. Materials

The waste groundnut shell and ant hill were collected in Delta State, Nigeria. The River Niger sand was obtained in the beach of Idah, Kogi state, Nigeria.

B. Method

The waste groundnut shell was packed in a graphite crucible and placed inside a muffle furnace with temperature maintained at 1300^{o}C for 4hours. After the groundnut shell was turned into ashes, ball milling was carried out using a Retsch planetary model: PM 400 and same was equally used for pulverizing the ant hill. Impurities were removed from the sand by washing with clean water and sun dried for 24hours. The ant hill was soaked in water containing oxalic acid solution for three weeks to remove dead organic matters and major impurities, washed several times with water and sun-dried for 24hours.

The moulding was prepared using a sand mixture of GSAp of percentage 2 to 14 and AHp 5 to 30. A roller miller was used to mix the formulation together. The mixture was moulded into standard specimens and classified for tests. The samples were furnace baked at 100-300°C for 1-5hours (see Figure 1). Testometric strength machine was used in the determination of both the compressive and shear strengths. The samples were gripped at both ends before the test. A force to determine the compressive and shear strengths of the materials was respectively applied.

Figure 1: Photograph of produced samples in Furnace for baking

IV. Results And Disscusion

A. Green Compressive and Shear Strength

The green compressive and shear strengths increased as the wt% of GSAp/AHp rose from 2/0, 4/5, 6/10, 8/15, 10/20, 12/25 to 14/30% (see Figure 2). At 14/30% GSAp/AHp addition, an optimum value of 71.34kN/m^2 was recorded for the green compressive strength while 45.78kN/m^2 was recorded for shear strength. Comparable results were obtained in the work carried out by Seidu et al, [15], which reported on investigation of the effects of sawdust, coal dust and iron filling additives at varied proportions on some selected properties of moulding sand. The combination of 25% sawdust, coal dust and iron filling in the moulding sand was found to produce mould with optimum green compressive strength of 108.99 kN/m2 and green shear strength value of 54.49 kN/m2.

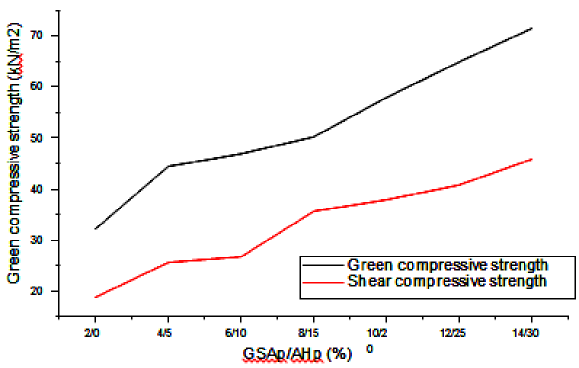

Figure 2: Plot of Green strength against GSAp/AHp addition

B. Dry Compressive Strength

Figures 3-5 show the results of dry compressive strength. Figures 3-5 revealed that as GSAp/AHp addition increased from 2/0, 4/5, 6/10, 8/15, 10/20, 12/25 to 14/30% the compressive strength also increased in turn. As the temperature increased from 100 to 300^{o}C, it took shorter time for the samples to be baked indicating that increases in temperature lead to quick bonding for the formulation. Also, it was observed that increases in the wt% of GSAp and AHp resulted in an increase in baking time. At 14/30% GSAp/AHp addition, the maximum baked compressive strengths of 356.7, 355.0, 335.3 kN/m^{2} were obtained at 5, 2, 1hours respectively. This baked compressive strength value at optimum agrees very well with standard value in Table 1 needed for nonferrous and iron castings [16].

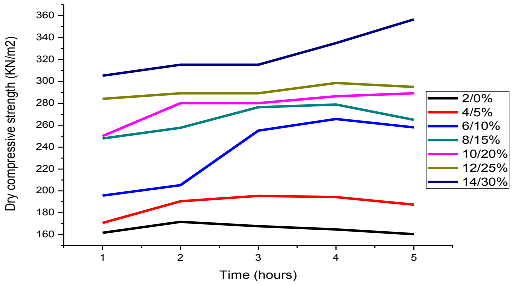

Figure 3: Plot of dry compressive strength against GSAp/AHp baked at 100^{o}C

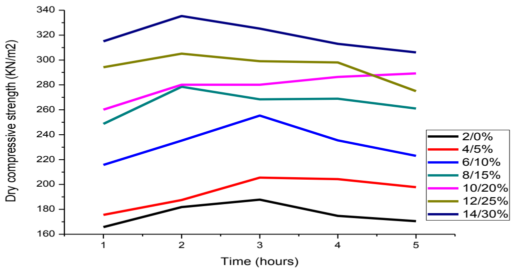

Figure 4: Plot of dry compressive strength against GSAp/AHp baked at 200^{o}C

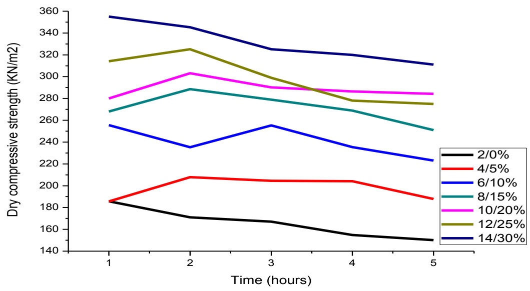

Figure 5: Plot of dry compressive strength against GSAp/AHp baked at 300^{o}C

Table 1: Satisfactory Mould Property Ranges for Sand Castings[16]

Metal	Permeability (ml/min)	GCS kN/m^{2}	DCS kN/m^{2}
Heavy steel	130-300	70-85	1000-2000
Light steel	125-200	70-85	400-1000
Heavy grey iron	70-120	70-105	50-800
Alumimium	80-100	50-70	200-300
Brass and bronze	60-90	55-65	200-860
Light grey cast iron	75-120	50-85	200-550
Present work	71-120	32.10-71.34	161-355

4.2.1Dry Compressive Strength for Optimal Setting

Taguchi design method of $L_9(3^3)$ was used to determine the optimal conditions of the dry compressive strength. The signal to noise ratio (S/N) was determined using a Minitab 16 software. Noise matrix involving the use of the outer orthogonal arrays were not considered since it was assumed that the noise effect was negligible and that by randomization of the inner array during the experimentation the noise effect was minimized. Equation 1 [17] was used to determine the S/N ratio using the larger the better. Table 2 shows the various parameters used in the analysis.

$$\left(\frac{S}{N}\right)_{HB} = -10\log\left[\frac{1}{n}\sum_{j=1}^{R}\left(\frac{1}{x_j^2}\right)\right] \text{----------------} 1$$

Table 2: Parameter used for the analysis

Process Parameter Designation	Process Parameters	Level 1	Level 2	Level 3
A	%GSAp/AHp	2/0	8/15	14/30
B	Temperatures (^{o}C)	100	200	300
C	Time	1	3	5

The results of the S/N ratio and the various effects are presented in Table 3 and Figures 6-11. It was observed in Figures 6-11, that as %GSAp/AHp increased from 2/0 to 14/30% there were increases in the dry compressive strength. This was expected because addition of GSAp/AHp to an optimum of 14/30% served to increase the bonding between GSAp/AHp and the sand. As the baking temperature incrased from 100 to 300^{o}C, the dry compressive strength also increaed. Increase in baking time from 1 to 3hours increased the dry compressive strength; higher baking time above 3hours decreased the dry compressive strength. The decrease in dry compressive strength beyond 3hours may be attributed to weakness in bonding of the sand for long heating time.

Table 3: various factors and levels

Exp. No.	(A)	B(°C)	C(wt%)	Dry compressive strength kN/m²	S/N ratio
S1	1	1	1	161.70	44.17
S2	1	2	2	187.83	45.75
S3	1	3	3	150.10	43.53
S4	2	1	2	276.40	48.83
S5	2	2	3	261.00	48.33
S6	2	3	1	268.09	48.57
S7	3	1	3	356.70	51.05
S8	3	2	1	315.00	49.97
S9	3	3	2	355.00	51.01

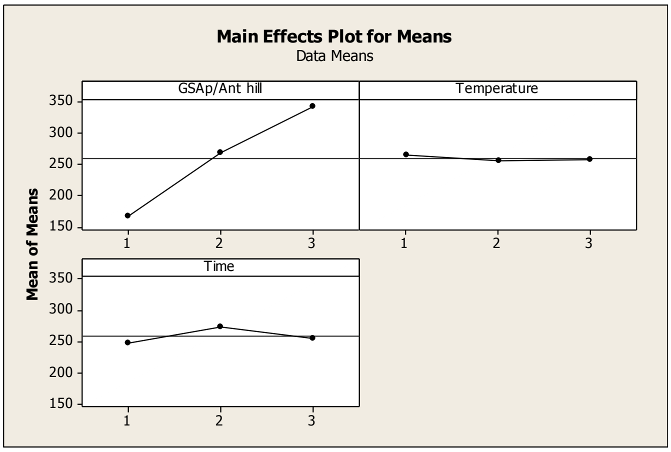

Figure 6: Main effects plot for the means

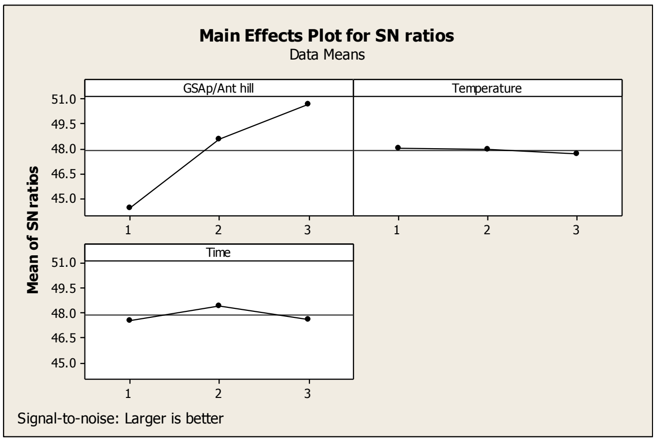

Figure 7: Main effects plot for the S/N ratios

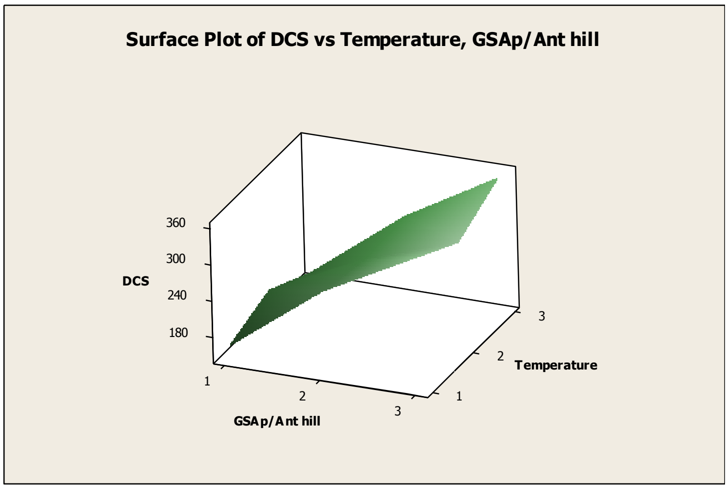

Figure 8: 3D plot of dry compressive strength (DCS) with interaction of GSAp/Ant hill and temperature

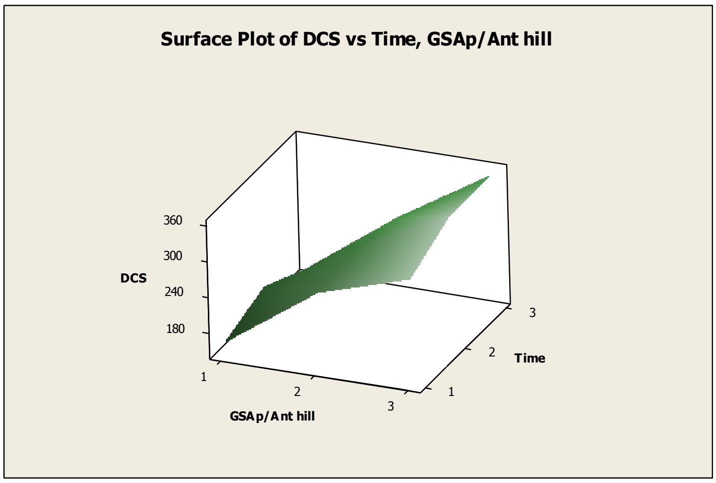

Figure 9: 3D plot of dry compressive strength (DCS) with interaction of GSAp/Ant hill and time

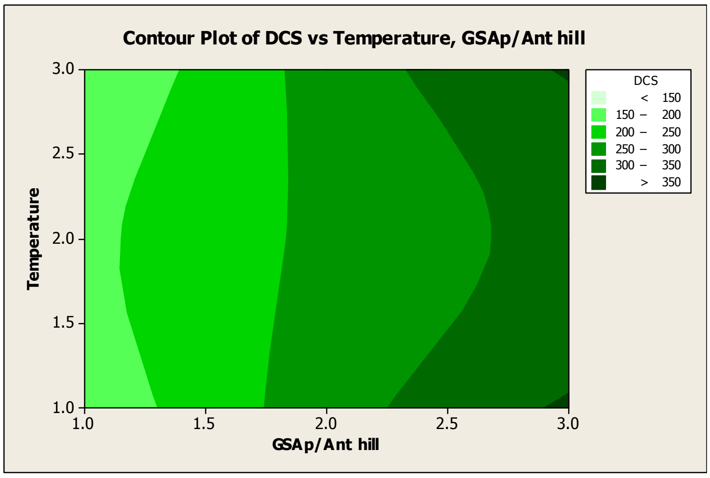

Figure 10: Contour plot of dry compressive strength (DCS) with interaction of GSAp/Ant hill and temperature

Table 4: Table for the response Means effect (Larger is better)

Level	GSAp/AHp	Temperature	Time
1	166.5	264.9	248.3
2	268.5	254.6	273.1
3	342.2	257.7	255.9
Delta	175.7	10.3	24.8
Rank	1	3	2

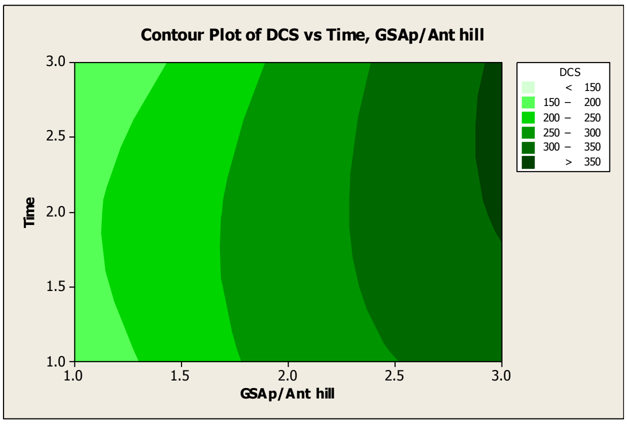

Figure 11: Contour plot of dry compressive strength (DCS) with interaction of GSAp/Ant hill and time

4.2.2Optimum Characteristics Estimate

Equation 2, [17] was used to determine the optimum condition for the analysis using S/N ratio at various levels and conditions.

$$\text{Factor} = \frac{A_1 + A_2 + A_3}{3} \quad \text{---------------2}$$

Tables 4-5 show the ranking of the analysis using the mean effects and S/N ratio. It is clearly seen that the greatest effect on the dry compressive strength is GSAp/AHp (rank 1), followed by time (rank 2) and then temperature (rank 3) - see Tables 4-5. The optimal condition for the dry compressive strength for the selected factors and levels was achieved at GSAp/AHp - L3, time - L2, and temperature - L1.

Table 5: Table for response Signal to Noise Ratios (Larger is better)

Level	GSAp/AHp	Tempewrature	Time
1	44.39	48.02	47.57
2	48.58	47.92	48.44
3	50.67	47.70	47.64
Delta	6.28	0.32	0.87
Rank	1	3	2

4.2.3Analysis of Variance (ANOVA)

ANOVA was used to determine which of the parameters that have the greatest effect. 95%conflidence levels were used to analyze the ANOVA using minitab 16. Table 6 depicts the ANOVA results. The results clearly show that GSAp/AHp has the greatest effect of 97.61%, and then time 2.03% and the least temperature 0.35%. The "Pred R-Squared" of 98.26 was close to the "Adj R-Squared" of 93.06%.

Table 6: Result of ANOVA

Source	Sum of Squares	DF	Mean square	F_{value}	P_{value}	%Contribution
GSAp/AHp	46717.1	2	23358.5	55.25	0.018	97.61
Temperature	168.5	2	84.2	0.20	0.834	0.35
Time	969.1	2	484.5	1.15	0.466	2.03
Residual	845.5	2	422.7			
Cor Total	48700.01	8				

4.3 Dry Shear Strength

The result of the dry shear strength is shown in Figure 12. The additions of GSAp and AHp into the sand significantly increased the baked shear strength. The shear strength of 78.12, 110.00, 123.00, 145.60, 154.67, 158.90 and 168.9kN/m^2 were obtained at 2/0, 4/5, 6/10, 8/15, 10/20, 12/25, 14/30% GSAp/AHp addition accordingly. From Figure 12, it was observed that good quality can be produced from sand mixes containing 14/30% GSAp/AHp addition.

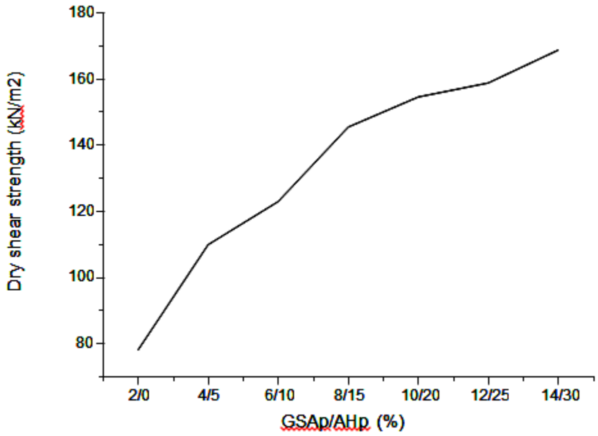

Figure 12: Plot of dry shear strength against GSAp/AHp

V. Conclusions

From the analysis above, the following can be deduced:

1. At 14/30% GSAp/AHp addition, the maximum baked compressive strength of 356.7, 355.0, 335.3 kNm^2 were obtained at 5, 2, 1hours respectively.
2. GSAp/AHp has the greatest effect of 97.61%, time 2.03%, and the least temperature 0.35% on the dry compressive strength.
3. The shear strength of 78.12, 110.00, 123.00, 145.60, 154.67, 158.90 and 168.9kN/m^2 were obtained at 2/0, 4/5, 6/10, 8/15, 10/20, 12/25, 14/30% GSAp/AHp
4. The optimal condition for the dry compressive strength for the selected factors and levels was achieved at GSAp/AHp - L3, time - L2 and temperature L - 1.

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