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FACTORS IDENTIFICATION FOR COAL BRIQUETTES MANUFACTURING USING STATISTICAL EXPERIMENTAL DESIGN APPROACH

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ABSTRACT

Coal briquettes are mostly manufactured through conventional methods in developing countries including Pakistan. Shortages of energy resources across the globe have pushed companies to manufacture those products with least possible costs by using significant factors. Indeed, the role of statistical design of experiment in general and factorial design in particular is vital in identifying these significant factors in comparison to the conventional techniques. This paper provides a statistical approach towards manufacturing of coal briquettes in Northern Province of Pakistan. Binder composition, pressure, particle size, and coal type are analyzed for higher calorific value and compressive strength simultaneously. Experiments are conducted in order to obtain the response of desired variables for the given three levels of each factor. Full factorial design approach with analysis of variance (ANOVA) is deployed to get the optimum values of the response variables under the given conditions.

KEYWORDS: *Design of experiment, factorial design, calorific value, ANOVA, compressive strength*

INTRODUCTION

Energy is a main source of survival for countries across the globe in general and developing countries in particular in today's competitive environment. Different sources and alternatives are used to meet the energy requirements with the lowest possible cost and least consumption of these resources. Solar energy and wind energy has been focused in the last few decades in addition to nuclear and other most common forms of energies. Coal energy is also among them. Coal has also been used as a major source of energy across the world. It has been considered as a reliable energy source to generate electricity. Coal has been used to generate electricity for more than 40 % of the total world requirement[1]. This fossil fuel resulted from plants that were concealed long time ago. Variation in temperature at much higher levels, difference of pressure conditions below the surface of earth, and chemical and physical transformations results in the formation of coal[1].

Coal briquettes continues to be used as a source of energy to meet the domestic and industry requirements. Different approaches and techniques are used to get more energy in the form of heat from the available coal briquettes. Benk and Coban[2] used various types of hardeners (i.e., ammonium nitrate, ammonium carbonate and nitric acid for the production of briquettes from anthracite fines). In their research, they found that 2.5% ammonium nitrate gave the best results. However, it was observed that the briquettes produced using 2.5% ammonium nitrate were having less strength. In addition, those briquettes were not water proof and having relatively less strength.

The role of experimental design approach in the identification and optimization of process parameters has been highly significant over the last few decades. The results are highly interesting and practicable for the industrial managers in order to optimize their process parameters. Bursali et. al.,[3] used experimental design approach for identification and optimization of factors that affect Saponification reaction.

Beauchamp et. al.,[4] investigated cutting parameter effects on surface roughness in a lathe dry boring operation. In their research, they deployed a full factorial design in order to determine the effects of six (6) independent variables. Those six independent variables were cutting speed, feed rate, depth of cut, tool nose radius, tool length and type of boring bar.

Wu et. al.,[5] studied that indoor air quality is affected by volatile organic compound (VOC) pollutants and these are often emitted by furniture and building materials. To enhance indoor air quality, removing VOCs from indoor environment is an important task. Tri-ethylene glycol (TEG) solution was used as working solution to absorb

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VOCs from ambient air in this study. Plastic 5/8 inches polaring-type was packed in the packed-bed absorber, and the packed length was about 34 cm. Toluene, methanol, ethyl-ether, and methyl-ethyl ketone were absorbed separately by TEG solution. They deployed Two-level factorial experimental design to schedule the operating variables. They concluded that air flux has a significant effect on mass transfer coefficient.

In Pakistan, coal briquettes are commonly used as source of energy in a number of local industries and for domestic purposes. The energy is attained through the formation of coal briquettes. This research is a leap forward in improving quantity of energy gained through a UN common source of energy called coal briquettes by using statistical experimental design approach. Coal has been used due to several reasons including its cheap price and availability of this source in abundance in most parts of Khyber Pakhtunkhwa, Pakistan. However, it has been criticized over its ability that lack in ignition and its low calorific value. Design and production of coal briquettes should be such that it would increase the ignition ability and calorific value of coal. Coal briquettes are produced to improve the calorific value and combustibility. The motivation behind this research is the energy crises across the globe, low prices of coal in comparison to other alternatives, and low manufacturing cost.

Section 2 explains the experiential setup used to manufacture the coal briquettes. Section 3 is related to the design and analysis of experiments approach for the data obtained in second section in addition to results discussion. Last section presents conclusions and future directions.

2. EXPERIMENTAL SETUP

The coal briquette manufacturing process layout is shown in Figure 1. The identification numbers in Figure 1 are illustrated in Table 1, which illustrates the process of coal briquettes manufacturing steps. Figure 2 shows the apparatus used as machine for coal briquettes.

Figure 2 and Table 2 highlights the working mechanism of the machine used in the coal briquettes. In this first step, coal in its raw form was crushed in a Jaw mill crusher, which converted the raw form of coal to fine powdered form. This fine powder form was then screened

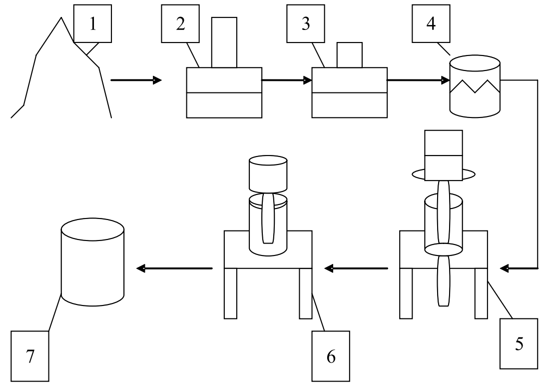

Figure 1. Coal briquette manufacturing process

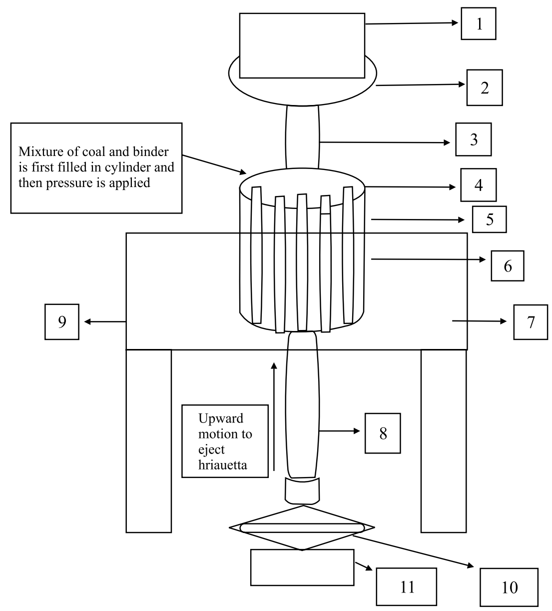

Figure 2. Coal briquette manufacturing machine

Table 1. Steps involved in Coal briquette manufacturing

S No	Apparatus	Function of apparatus
1	Coal extraction from mines	Coal is extracted here
2	Crushing machine	Coal is crushed in to powder form
3	Screening machine	Coal is screened in to different particulate sizes
4	Binder mixing jar	Binders are mixed with coals
5	Coal briquette machine i	Application of apparatus and briquette preparation
6	Coal briquette machine ii	Coal briquette is extracted from machine
7	Coal briquette	Complete coal briquette

and different particle size coal samples were obtained. Apparatus used for this purpose was a screening machine that separate the coal in 0.675mm, 0.500mm, 0.375mm particle sizes. Appropriate amount of filler and binding material required to make coal briquette is mixed with sufficient coal to manufacture brick weighing 650 grams. The material was then fed to briquette machine and appropriate constant pressure was applied to the material for 15 to 20 minutes. After that briquette were removed from the machine and detached from piston. Briquette was then placed in sun light for drying purposes and to enhance its bonding strength.

Table 2. Coal briquette machine

S No	Apparatus	Function
1	Weight	Used to apply pressure on coal briquette
2	Weight carrying platform	Supports the weight
3	Piston rod of pressure piston	Attached to pressure piston
4	Pressure piston	Applies pressure on coal briquette to get desired shape
5	cylinder rods to make holes in briquette	Make holes in the briquette
6	Cylinder	Contain whole apparatus and coal briquette mixture with binder
7	Coal briquette machine table	Main support to whole apparatus
8	Ejection piston rod	Attached to ejection piston
9	Ejection piston	Moves upwards and eject coal briquette
10	Mechanical jack	Moves ejection piston upwards
11	Base	Support for ejection piston

3. Statistical Analysis using factorial design approach.

Based on the end-user requirements and literature survey two types of response variables were selected (calorific value and compressive strength). Calorific value represents the amount of heat produced when a quantity of briquette is burnt. Similarly, compressive strength is the amount of pressure that a briquette can withstand without breaking/failure. Optimization of these two variables is expected to result in more energy with less investment.

The role of binders composition in briquette manufacturing cannot be ignored. Different binders are used across the world to increase the required parameters. Different binders' data was collected in regard to strength and calorific value for a particular type of coal. Sample based analysis was performed and results were obtained as follow

It was observed that the combination of polyvinyl acetate (PVA) with $CaCO_3$ as filler results in best results with higher calorific values and strength.

Table 3. Binder selection

S No	Sample Type	Calorific Value (joules)	Compressive strength (tons)
01	Sample Type 1 = Coal + PVA + CaCO3	32640	0.19
02	Sample Type 2 = Coal + PVA (1000ml)	30450	0.15
03	Sample Type 3 = PTC Briquette	16232	0.185
04	Sample Type 4 = Phoenix Briquette	24523	0.17

Following four types of potential design factors were taken into consideration.

1. Binder Composition
2. Particle size of coal
3. Pressure applied for briquette manufacturing
4. Type of coal used.

Briquette design parameters were considered as fixed during the experimentation process. It mainly includes the wright of the briquette, number of holes, shape, and holes pattern in the briquette. However, few factors including moisture level, drying time, and atmospheric conditions were considered as uncontrollable factors.

Following levels were defined for the experimentation purposes of the designed factors.

1. Binder Composition level (Factor I)

b. 30 ml (1000 ml PVA)

c. 45 ml

d. 60 ml

2. Particulate Size (Factor II)

a. 0.625 particle size

b. 0.375 particle size

c. 0.50 particle size

3. Pressure (Factor III)

a. 10 kg = 98 N

b. 15 kg = 147 N

c. 20 kg = 196 N

4. Coal type

a. Dara Adam Khel coal (Coal Type 1)

b. Doaba coal (Coal Type 2)

c. Hangu coal (Coal Type 3)

In order to reduce the number of factors and make the DOE model more concise and robust for analysis "one factor at a time approach" was used[6] to conclude about the type of coal used. In this experimental process, binders values were kept constant i.e., 1000ml PVA. Only experiments were conducted by changing the coal types. Three types of coal were analyzed as follows:

Table 4. Coal type selection

Coal Briquettes Sample	Avg. Moisture Level (%)	Avg. Ash Content (%)	Avg. Fixed Carbon (%)	Avg. Calorific Value (joules)	Avg. Tensile Strength (ton)
Coal type 1 + binders.	1.35	24	63	30463	0.19
Coal type 2 + binders	1.30	32	48.12	23268	0.175
Coal type 3 + binders	1.7	47	36.45	22251	0.145

Based on the average calorific value and average tensile strength, coal type 1 (from Darra Adem Khel) was considered to be the best among these three available alternatives.

Therefore, the problem is reduced the three factors with each factor at three level. Coal type 1 was taken into consideration for all rest numerical computation and analysis.

Following three factorial ANOVA model was used for the analysis

$$y_{ijkl} = \mu + T_i + ß_j + \Upsilon_k + (T\beta)_{ij} + (T\Upsilon)_{ik} + (ß\Upsilon)_{jk} + (T_iß\Upsilon)_{ijk} + \varepsilon_{ijkl}$$

where

$T_i + ß_j + \Upsilon_k$ represents main factor and $(T_i\beta)_{ij} + (T_i\Upsilon)_{ik} + (ß\Upsilon)_{jk}$ shown the interaction effect among two factors. $(T_iß\Upsilon)_{ijk}$ shows the interaction among all the three factors.

Following Table 5 along with data set was generated using Minitab 16 version.

Furthermore it can be observed from the normality graph that the data set obtained remain normal.

Based on the ANOVA Table 6 and above Figures (4-7) related to the main effects plot and interation plots, following recommendations can be made.

The impact of binder composition and pressure on the compressive strength remain highly significant. However, the effect of particle size remain less significant on the compressice strength. Similarly, the interation effect

Table 5. Randomly generated dataset for the Factorial Design problem

Particle Size	Binder Composition	Pressure (Kg)	Calorific Value (J)	Compressive Strength (ton)
0.625	60	10	27200	0.06
0.5	30	20	25643	0.017
0.375	45	10	28120	0.082
0.5	45	10	27200	0.057
0.375	45	20	31900	0.183
0.5	60	20	25600	0.2
0.375	60	15	30150	0.135
0.5	60	10	24300	0.127
0.375	30	20	26900	0.04
0.5	30	10	25400	0.012
0.625	45	15	28600	0.109
0.375	60	10	28412	0.105
0.5	60	15	25800	0.1
0.375	60	20	32300	0.34
0.375	45	15	26141	0.139
0.5	45	20	31400	0.147
0.625	60	20	27800	0.295
0.375	30	15	26450	0.037
0.625	30	15	28150	0.021
0.625	30	20	29300	0.035
0.625	45	10	26200	0.037
0.5	30	15	26400	0.015
0.625	45	20	29000	0.12
0.625	30	10	28120	0.01
0.625	60	15	31500	0.135
0.5	45	15	30600	0.139
0.375	30	10	25641	0.015

of pressure applied and binding compostion on compressive strength was also significant in comparison to other interations. All recommendations are made based on 5% alpha.

On the other side, the impact of all these three factors on the calorific value remain significant. Pressure remian highly significant in comaprison to binder compostion and particle size. Furthermore , binder composition and particle size had significant inetartion effect on the calorific value. The other two interation are less significant at 5% alpha.

4. CONLUSIONS

This paper focuses on statitical aspect for the manufactring of coal briquittes in Pakistan, in particular. Design of experiment in general and factorial design principles in a particle have been considered very rarely in siginifiacnt factors identification for manufacturing processes. This paper highlighted the significant factors in manufacturing of coal briquetts in regard to optimization of two response variables simultaneously. Calorific value and compressive strength has been optimized for the given levels of three factors including binder composition, particle size, and pressure applied during the manufacturing of coal briquetts. All the three factors remained significant for the calorifc value. However, the impact of particle size on the

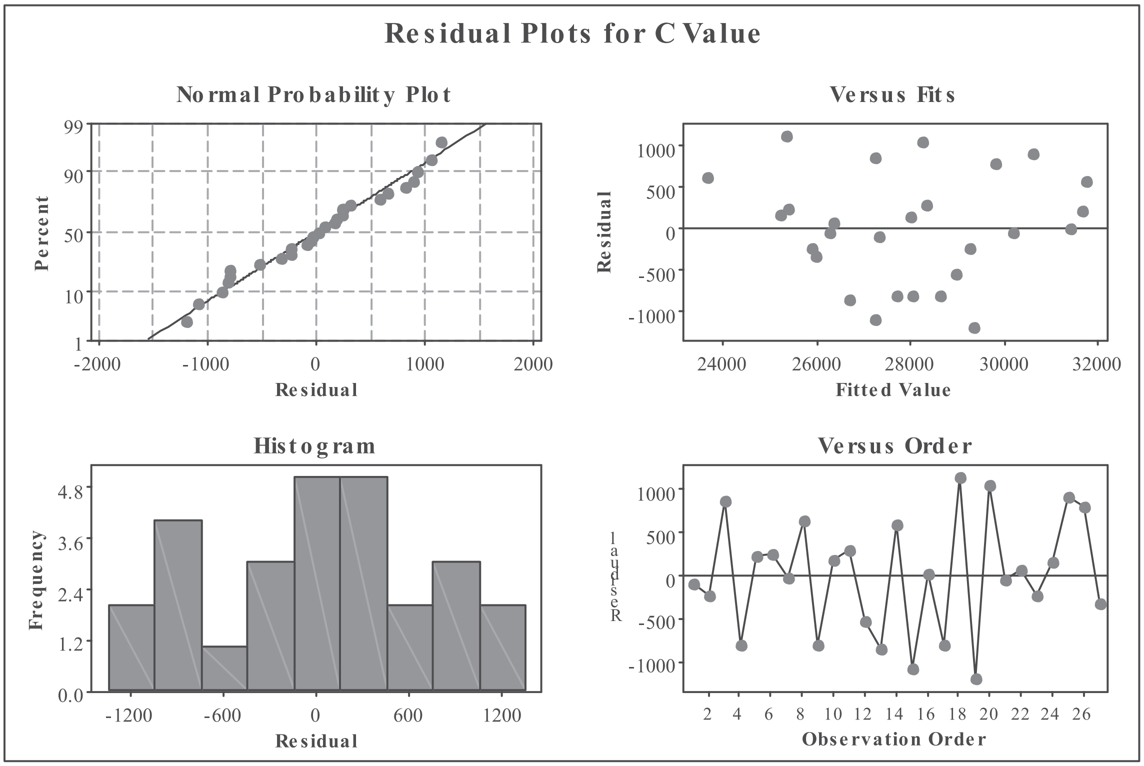

Figure 3. Residual analysis for data set in Table 5.

Table 6. ANOVA

Factor	Type	Levels	Values
Binder Composition	fixed	3	30, 45, 60
Pressure	fixed	3	10, 15, 20
Particle Size	fixed	3	0.375, 0.500, 0.625

Analysis of Variance for Comp. Strength, using Adjusted SS for Tests					
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**
Binder Composition	2	0.0951482	0.0951482	0.0475741	65.32
Pressure	2	0.0431562	0.0431562	0.0215781	29.63
Particle Size	2	0.0049342	0.0049342	0.0024671	3.39
Binder Composition*Pressure	4	0.0285556	0.0285556	0.0071389	9.80
Binder Composition*Particle Size	4	0.0025809	0.0025809	0.0006452	0.89
Pressure*Particle Size	4	0.0042029	0.0042029	0.0010507	1.44
Error	8	0.0058267	0.0058267	0.0007283	
Total	26	0.1844047			
Source	P				
Binder Composition	0.000				
Pressure	0.000				
Particle Size	0.086				
Binder Composition*Pressure	0.004				
Binder Composition*Particle Size	0.514				
Pressure*Particle Size	0.305				

S = 0.0269877 R-Sq = 96.84% R-Sq(adj) = 89.73%					
Analysis of Variance for C Value, using Adjusted SS for Tests					
Source	DF	Seq SS	Adj SS	Adj MS	F
Binder Composition	2	16808882	16808882	8404441	5.80
Pressure	2	21532460	21532460	10766230	7.42
Particle Size	2	13699878	13699878	6849939	4.72
Binder Composition*Pressure	4	10012730	10012730	2503182	1.73
Binder Composition*Particle Size	4	44216878	44216878	11054220	7.62
Pressure*Particle Size	4	10533688	10533688	2633422	1.82
Error	8	11601312	11601312	1450164	
Total	26	128405828			
Source	P				
Binder Composition	0.028				
Pressure	0.015				
Particle Size	0.044				
Binder Composition*Pressure	0.237				
Binder Composition*Particle Size	0.008				
Pressure*Particle Size	0.219				

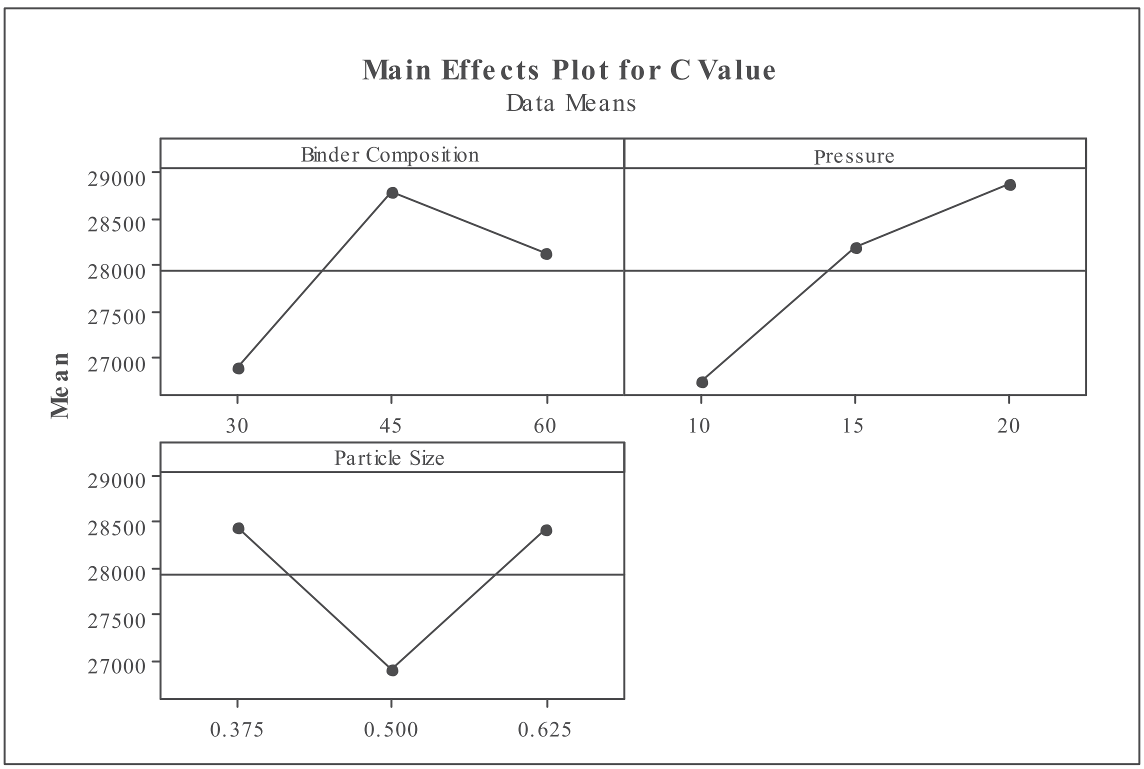

Figure 4. Main plot for response variable (Calorific Value)

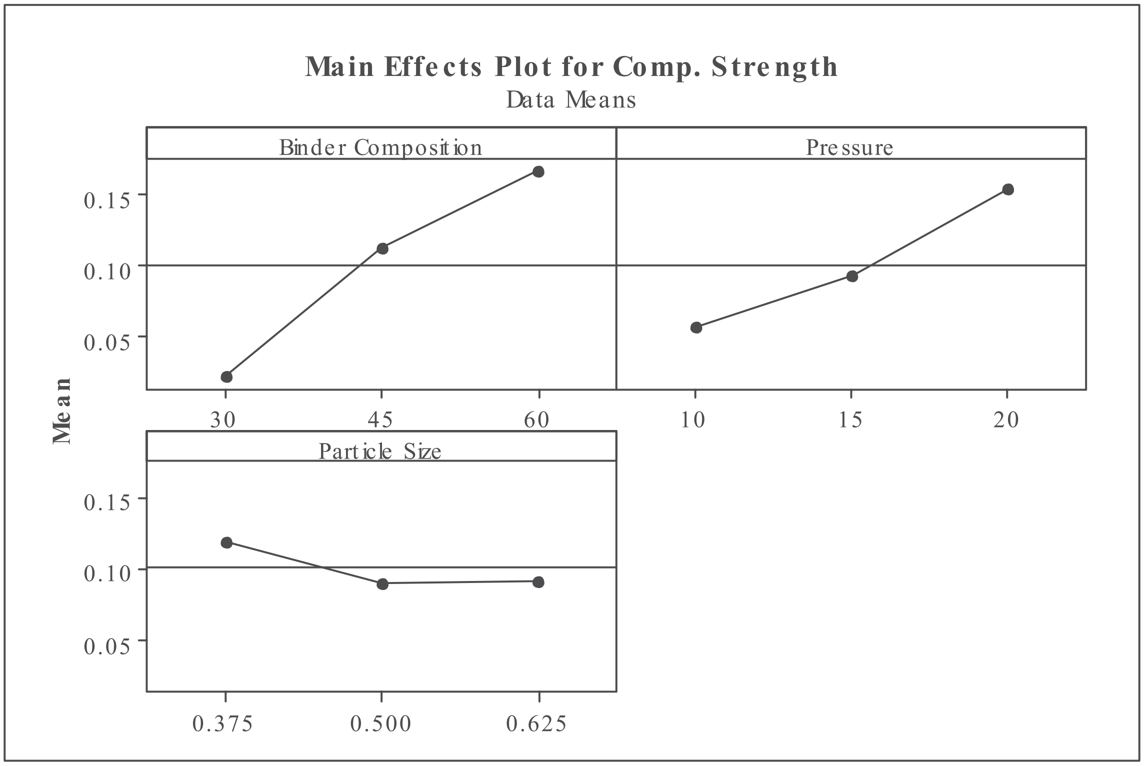

Figure 5. Main plot for response variable (Compressice Strength)

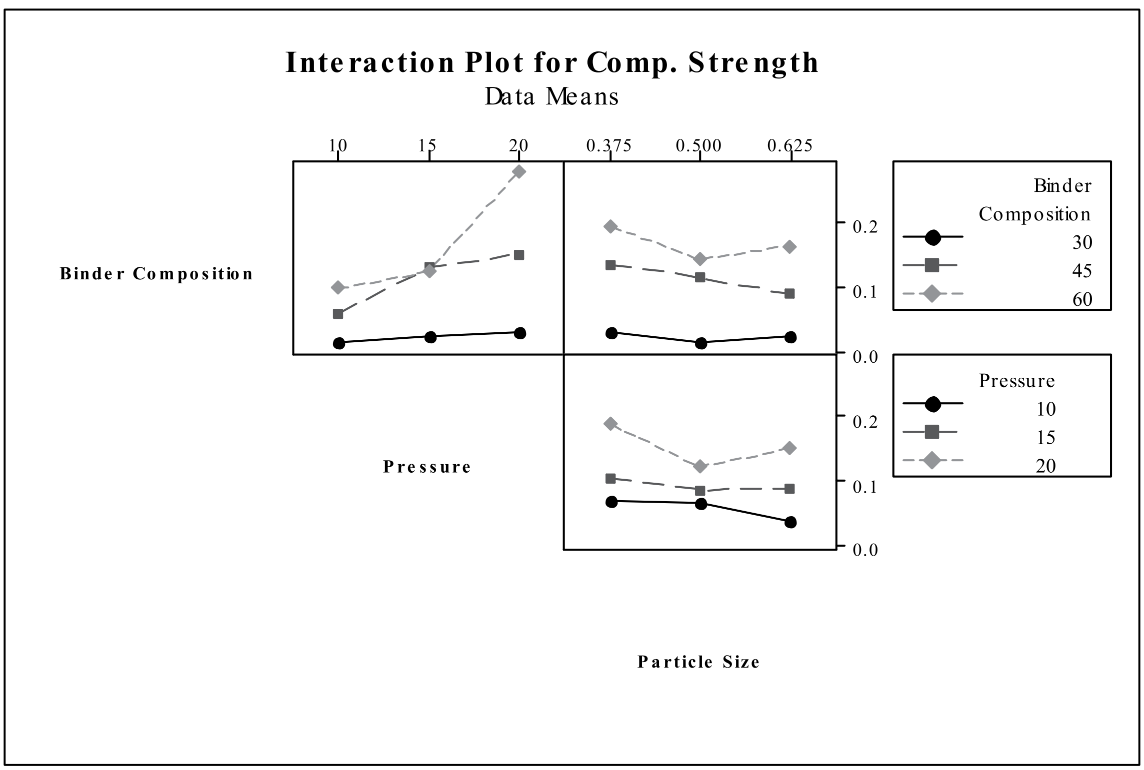

Figure 6. Interation plot for response variable (Compressive Strength)

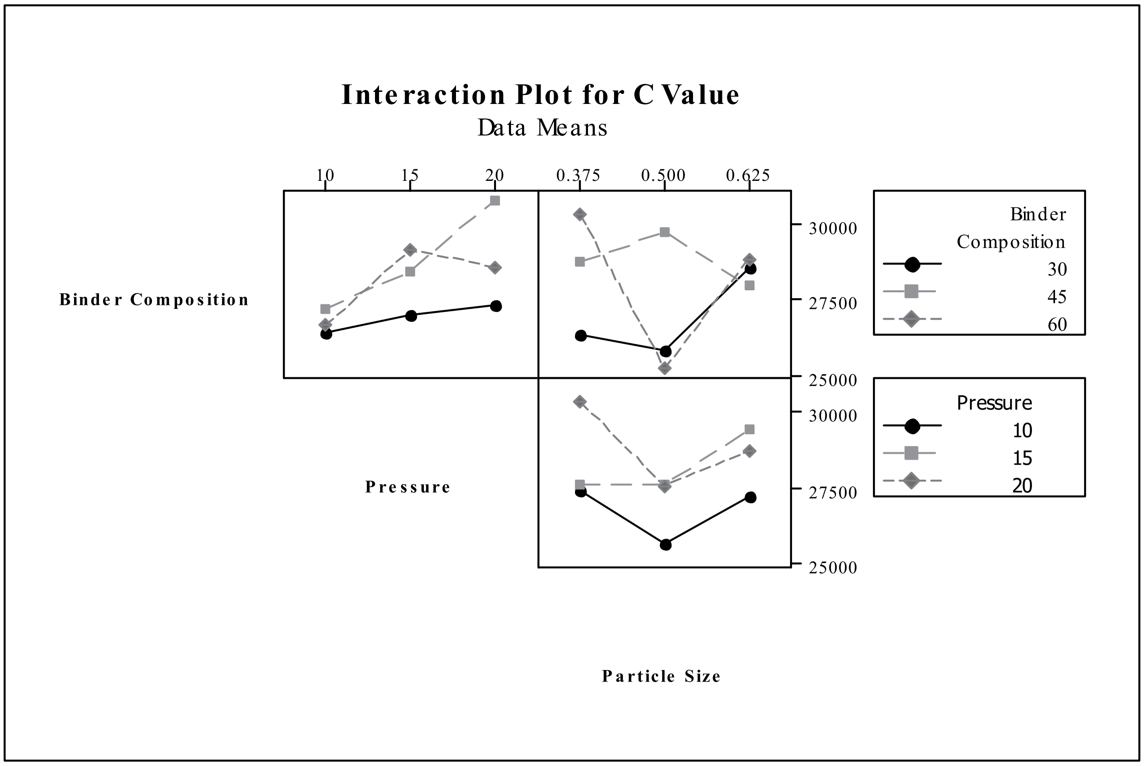

Figure 7. Interation plot for response variable (Calorific Value)

comparessive strength remains less significant. The paper provide an insight to manufacturers to consider these appraches while developing such type of manufcaturing products. The paper can be further extended by taking fixed factors into considerations. Taguchi method can also be deployed for identifcation of significant factors. The research can be futher extended by taking sample data from other regions of Pakistan.

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