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Utilizing of the Statistical Analysis for Evaluation of the Properties of Green Sand Mould

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Abstract

A statistical approach was conducted to investigate effect of independent factors of the mixing time compactability and bentonite percentage on dependent variables of permeability, compression and tensile strength of sand mould properties. Using statistical method save time in estimating the dependent variables that affect the moulding properties of green sand and the optimal levels of each factor that produce the desired results.

The results yielded indicate that there are variations in the effects of these factors and their interactions on different properties of green sand. The outcomes obtained a range of permeability values, with the highest and lowest numbers being 125 and 84. The sand exhibited high values of tensile and compressive strength measuring at 0.33N/cm^2 and 17.67N/cm^2. Conversely it demonstrated low levels of tensile and compressive strength reaching 0.14N/cm^2 and 9.32N/cm^2.

These results suggest that the moulding factors and their interactions have an important role in determining properties of the green sand.

ANOVA was used to assess effect of various factors on different properties of the green sand. The results obtained suggest that compactability factor play a significant effect on permeability, the mixing time or bentonite factor has a significant effect on the compressive strength and mixing time or compactability factor has a significant impact on the tensile strength with a significance level lower than 5%. It is found that neither the mixing time nor the amount of bentonite used in the green sand mix has a significant impact on its permeability. Compactability of the green sand does not has a significant effect on the compressive strength. Bentonite used in green sand mix does not have a significant impact on its tensile strength.

Keywords: Green sand, Mixing time, Compactability, Compressive strength, ANOVA.

1. Introduction

Sand moulds characterized by ease of the mould making process, and ability of recycle of the moulding sand [1,2]. Silica sands is the most refractory material used as a moulding mixture for casting production, because materials and patterns are relatively cheap [3, 4]. The natural sand and the synthetic sands are two kinds of sands [5]. Sand moulding process involves mixing of sand, bentonite, and water to make green sand moulds [6]. Water content affects the properties of green sand such as permeability, bulk density, shear strength, dry and green compression strength [7]. The grain size and shape of sand, type, water content, the mixing process efficiency, cohesive forces of bentonite binder, and adhesive forces between, pattern and moulding sand are necessary parameters that determine green sand properties [8, 9]. Mixing process of the green sand improves density of the sand mould by connecting of sand and bentonite particles together [10].

Variation of water content and bentonite content has played an important role in determining the properties of bentonite-bonded green sand. Green Compression strength of the sand mould is an important property in mould production, and depends on sand grain size, shape and distribution, water content, kind and bentonite content [11]. Increase of water content enhance compression strength of the green sand until constant value, afterward decrease in this property as a result of increase in water content. Fine grain size of the sand and high value of bentonite content support increases green compression strength, while coarse grains contribute in reduce of green compression strength of the sand [12, 13]. Ability of the green sand to be mould require at least 10.34 kpa of the compression strength [6]. Design Of Experiments (DOE) is important tool used for determining the responses depend on inserted input-output data. Response Surface Methodology (RSM) is an experimental design and statistical tool, during which dependent properties respond into change in one or more independent variables [14, 15]. Abdulamer [16] used Taguchi method to determine the effective moulding parameters for improving green sand mould properties. The study was conducted through an experimental design to investigate the effects of several molding variables on the compression strength, tensile strength, and permeability of green sand. The molding variables considered in this study are compactability percentage, mixing time, and bentonite content.

The study utilized a factorial design of experiments, which is a statistical approach that allows for the efficient exploration of multiple factors and their interactions. In this design, the molding variables are varied at different levels, and the response variables are measured for each combination of factor levels.

2. Design of Experiments

The sand samples were prepared using a mixing machine to combine sand, bentonite, and water in the appropriate ratios based on a design of experiments that mentioned in tables 1 and 2. It is important to ensure that the sand samples are prepared accurately and consistently in order to obtain reliable results from the testing processes. This may involve careful measurement and monitoring of the mixing process, as well as ensuring that the sand, bentonite, and water are of a consistent quantity. Once the sand samples have been prepared, they can be subjected to various testing processes to evaluate their properties in relation to different moulding factors. The tests are permeability, compressive strength, and tensile strength that can affect the quality and performance of sand moulds in different applications.

A standard test procedure used in foundries for measuring the properties of green sand. The first step of the procedure involves filling a tube with a measured mass of prepared mixed sand. The tube has a diameter of 50mm and a height of 100mm. Next, the sand is compacted by subjecting it to three strikes from a ramming machine. This compaction process is important because it ensures that the sand is of a consistent density and will produce reliable test results. After the sand has been compacted, it is removed from the tube and formed into standard sand samples. These samples have a diameter of 50mm and a height of 50mm. These sand samples are then used to measure permeability and mechanical properties of green sand. The permeability is measured using a permeability gauge as shown in figure 1 which determines how easily air can pass through the sand. The mechanical properties are measured using a Universal Sand Strength Testing Machine (USSM) as shown in figure 2 which measures the strength and deformation characteristics of the sand. This test procedure is an important tool for ensuring that green sand used in foundries is of a consistent quality and will produce reliable castings.

Table 1.
Sand moulding factors & their levels

Levels	Factors		
	Compactablity %	Mixing Time (min)	Bentonite content %
1	34	2	5
2	39	4	7
3	44	6	9
4	49	8	11

Table 2.
Factorial Design

Trail. No	Compactability %	Mixing Time (min)	Bentonite %
1	34	2	5
2	34	4	7
3	34	6	9
4	34	8	11
5	39	2	7
6	39	4	5
7	39	6	11
8	39	8	9
9	44	2	9
10	44	4	11
11	44	6	5
12	44	8	7
13	49	2	11
14	49	4	9
15	49	6	7
16	49	8	5

Fig. 1. Gauge of Permeability

Fig. 2. Universal sand strength testing machine

3. Results and Discussion

Design of experiments (DOE) is a statistical method used to evaluate the effect of mixing time, compactability and bentonite percentage on the properties of the green sand to identify the optimal levels of each factor to achieve the desired sand properties. Figures 3-5 show impact of different molding parameters on certain properties of a moulding material. Several experiments were conducted, and the properties being studied are permeability number, compressive strength, and tensile strength respectively. The results obtained from the experiments showed that the moulding factors and their interactions with each other have a varying impact on the properties of the sand mould.

The second experiment resulted in the lowest permeability value, which means that the green sand was least permeable in that experiment compared to the others. On the other hand, the maximum permeability property was observed in experiment number 13, indicating that the green sand was most permeable in that experiment compared to the others.

The compressive strength property was measured for each experiment, experiment number 7 and 16 resulted in the optimum values of compressive strength, indicating that the green sand had the highest compressive strength in those experiments compared to the others. Conversely, experiment number 1 had the lowest value of compressive strength, suggesting that the green sand had the weakest compressive strength in that experiment compared to the others.

The tensile strength of green sand was tested in a series of experiments, and that the highest and lowest values were obtained in experiments 16 and 1, respectively.

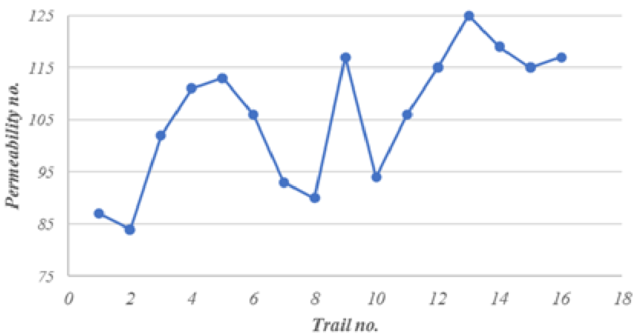

Fig. 3. Permeability number VS trail no

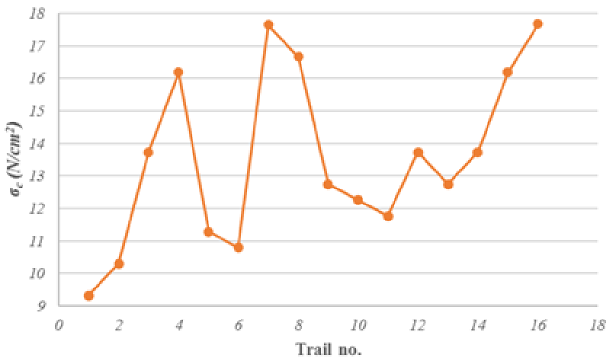

Fig. 4. Compressive strength VS trail no

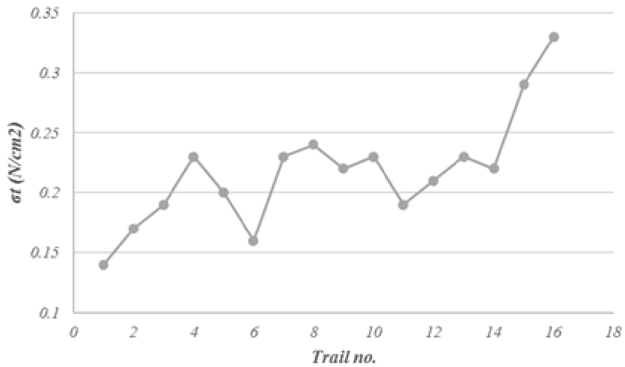

Fig. 5. Tensile strength VS trail no

The factors being analysed are compactability and mixing time, and the response variable is permeability of green sand. The interaction plot is shown in figure 6, displays how the effect of compactability on permeability changes at different levels of mixing time, and vice versa.

It is found that combination of 4th level of the compactability factor, and 1st level of the mixing time factor resulted in the highest values of permeability. The first level of compactability factor in combination with the second level of mixing time factor resulted in the lowest permeability value. This suggests that a specific combination of these two factors can lead to the most tightly packed and well-mixed green sand, which in turn reduces its permeability. On the other hand, the fourth and second levels of compactability factor show that permeability of the green sand decreases with an increase in mixing time levels. This could be due to the fact that increasing mixing time can lead to better distribution of the sand particles and binder, resulting in a more homogenous mixture that is less permeable. While, the first and third levels of compactability factor improved the permeability property with an increase in mixing time levels. This suggests that there may be an optimal range of mixing time for each level of compactability factor that results in the best permeability properties. The interaction plot shown in figure 7 between bentonite and mixing time may provide insight into how these two factors interact to affect permeability. The 4th level of bentonite and the 1st level of mixing time had the greatest impact on permeability, resulting in the highest permeability. In contrast, the 2nd levels of bentonite and mixing time had the lowest permeability values. It is also suggested that the other three levels of bentonite had a changing effect on permeability as the mixing time increased, except for the 1st level of bentonite which did not change with increasing mixing time. Overall, it seems that the level of bentonite and mixing time are both important factors that can influence green sand permeability. The specific levels of each factor can have a significant impact on the permeability value obtained. The results suggest that the 1st and 4th levels of bentonite had a consistent effect across the 2nd and 3rd levels of mixing time. The 3rd level of bentonite had a constant effect across the 1st and 2nd levels of mixing time, while the 2nd level of bentonite had a constant effect across the 3rd and 4th levels of mixing time.

4. Analysis of Variance

The study investigated impact of the different moulding factors on permeability of the green sand, which is used in foundry applications. Table 3 presents results of Analysis Of Variance (ANOVA) that performed on the data collected during the study. ANOVA is a statistical tool used for comparison means of two or more groups, to determine if there are statistically significant differences between them. In this case, ANOVA results for the different moulding factors (compactability, mixing time, and bentonite) indicate that there is a statistically significant variance in permeability for the compactability factor (P<0.05), but no significant differences for mixing time and bentonite (P>0.05) and equal means. Equation 1 presents a regression model that was developed to predict the permeability of green sand based on the different moulding factors. Regression analysis is a statistical technique used to identify relationship between dependent variable (permeability), and one or more independent moulding factors. Table 4 shows a comparing permeability values obtained through the regression equation, expected values by the design of experiments, and in practice.

Table 3.
ANOVA for factors- dependent- permeability

Source	DF	Adj. SS	Adj. MS	F.Value	P.Value
Compactability%	1	1170.45	1170.45	11.16	0.006
Mixing Time (min)	1	2.45	2.45	0.02	0.881
Bentonite %	1	6.05	6.05	0.06	0.814

Permeability Regression Equation = 86.3 + 7.65 Compactability - 0.35 Mixing Time + 0.55 Bentonite (1)

Table 4.
Comparison between used methods for determining permeability

Evaluation method	Compactability %	Mixing Time (min)	Bentonite %	Permeability no.
Predication	4	1	4	118.7
Practical	4	1	4	125
Regression	4	1	4	95.4

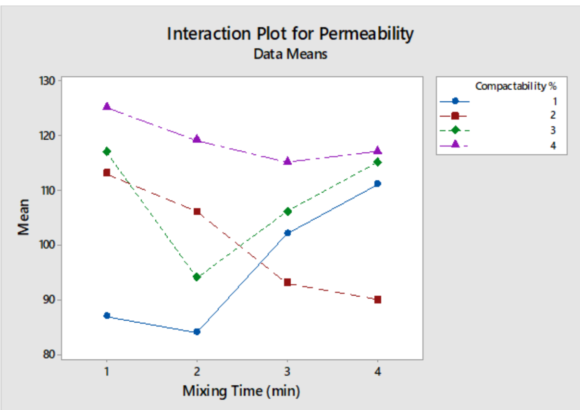

Fig. 6. Plot of interaction of compactability and mixing time for Permeability

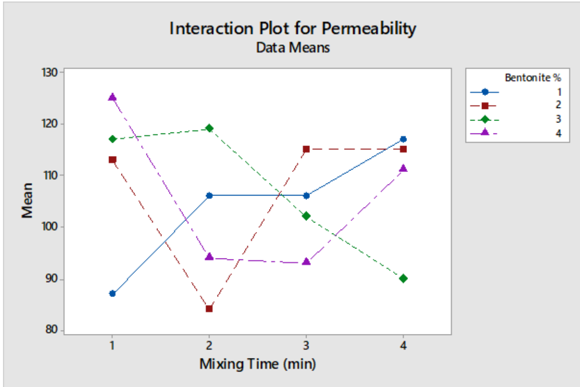

Fig. 7. Plot of interaction of bentonite and mixing time for Permeability

It is important to consider the design of the experiment that produced the plot and the statistical methods used to analyse the data, and the interpretation of the interaction plot may be influenced by other factors that were not mentioned. Figure 8 shows the interaction plot of compactability and mixing time showing that the fourth level of these two factors possess a positive influence on green compressive strength of sand. The highest value of the compressive strength is gained when the compactability factor is at 2^{nd} level and the mixing time is at 3^{rd} level, while the lowest value of compressive strength is achieved when the compactability and mixing time are at their 1st levels.

The plot shown in figure 9 was examines the relationship between bentonite, mixing time and their effects on compressive strength of the green sand. Excluding the 1^{st} level, the other three levels of bentonite and mixing time factors have enhance of the compressive strength of green sand. The experiments found that except for the 1^{st} level, the other three levels of bentonite and mixing time have been tested, and results showed an increase in the compressive strength of sand.

An analysis of variance (ANOVA) listed in table 5 for compressive strength of green sand shows that mixing time and bentonite have a significant effect on the strength, while compactability does not. This is indicated by the p-values, with those for mixing time and bentonite being less than 0.05 (which is the typical threshold for statistical significance), and the p-value for compactability being above 0.05 indicating no variances and equal means. Equation 2 listed the regression equation of compressive strength, and table 6 comparing values of property obtained through the regression equation, the expected value by the design of experiments, and in practice. Equation 2 has listed a regression equation that relates the compressive strength of the green sand to the moulding factors (mixing time, bentonite, and compactability), and table 6 compares the values of this property obtained through the regression equation, the expected value based on the design of experiments, and the actual values observed in practice. The observed values were found have a good match with the predicated and regression values.

Table 5.
ANOVA for factors dependent- compressive strength

Source	DF	Adj. SS	Adj. MS	F. Value	P. Value
Compactability%	1	6.915	6.915	3.54	0.084
Mixing Time (min)	1	50.721	50.721	26.0	0.00
Bentonite%	1	16.435	16.435	8.42	0.013

Compressive strength Regression Equation (N/cm^2) = 5.77 + 0.588 Compactability % + 1.593 Mixing Time (min) + 0.906 Bentonite % (2)

Table 6.
Comparison between used methods for determining compressive strength

Evaluation method	Compactability %	Mixing Time (min)	Bentonite %	Compressive strength (N/cm^2)
Predication	4	4	4	18.1155
Practical	4	4	1	17.57
Regression	4	4	1	23.33

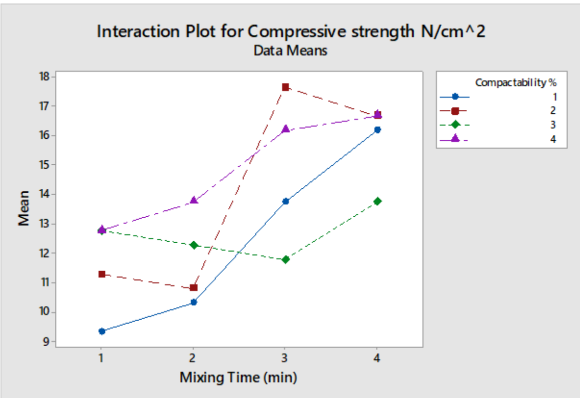

Fig. 8. Interaction plot of mixing time and compactability for compressive strength

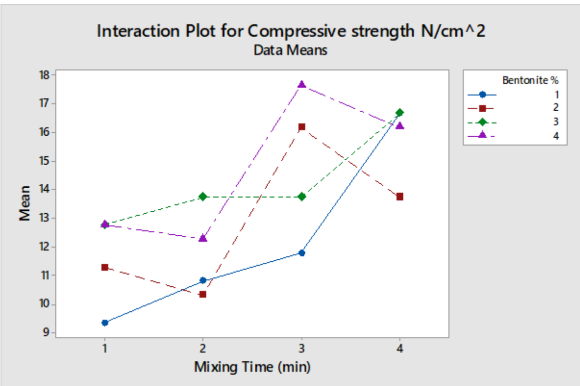

Fig. 9. Interaction plot of mixing time and bentonite for compressive strength

Figure 10, describes results of an experiment that investigate effects of compactability and the mixing time on tensile strength of the green sand. The results show that there is a significant interaction between compactability and mixing time, which affects tensile strength of the green sand. There are two levels of compactability (the 2nd and 4th levels) that have similar effects on tensile strength of the sand. In other words, changing the compactability from the 2nd level to the 4th level did not result in a significant change in the tensile strength. Additionally the mixing time has nonlinear effect on tensile strength of sand. Specifically, there was a decrease in tensile strength of green sand when shifting from 1st level to 2nd level of mixing time. However, after that, there was an increase in the tensile strength when shifting from the 2nd level to the 3rd and 4th levels of mixing time. Overall, these findings suggest that the optimal combination of compactability and mixing time can lead to the highest tensile strength of green sand.

There is a correlation between mixing time and compactability and tensile strength of green sand. It appears that 1st level of compactability shows clear behavior resulted in the highest tensile strength of sand with increase of mixing time. It is found that 1st level of factors of compactability and the mixing time gives negatively impact the strength of the sand. On the other hand, the 4th level of factors of compactability and mixing time resulted in the highest tensile strength, indicating that an optimal level of these factors was reached.

The relationship between bentonite and the mixing time factors and their impacts on tensile strength of green sand was shown in figure 11.

The first level of bentonite (the lowest level used in the experiment) had the same effect of compactability as the fourth level (presumably the highest level used) on the tensile strength. It is found that these levels of these two factors does not significantly improve tensile strength of sand. The second, and third levels of bentonite had varying effects on tensile strength of green sand. This implies that there is an optimal level of bentonite that can enhance the tensile strength. The highest tensile strength was observed when using the first level of bentonite and the fourth level of mixing time. This indicates that longer mixing time may lead to better bonding between the sand grains, resulting in higher tensile strength. The lowest tensile strength occurred with the first level of bentonite and mixing time. This suggests that inadequate bentonite content and/or mixing time may result in poor bonding and lower tensile strength.

Table 7 presents the results of analysis of variance (ANOVA) for the different parameters studied, on the tensile strength of the green sand. The significance P- values for mixing time and compactability were found to be less than 0.05, which suggests that there is a significant variance in the results for these factors. On the other hand, the significance value for bentonite was above 0.05, indicating that there was no significant variance and that the means were equal for this factor. Equation 3 presents a regression equation that was derived from the data obtained in the experiment, which can be used for prediction tensile strength based on the values of the different factors studied. Table 8 appears to compare the values of the tensile strength obtained through the regression equation, the expected values based on the design of the experiment, and the values obtained in practice. This comparison can help to evaluate the accuracy of the regression equation and the effectiveness of the experiment in predicting tensile strength.

Table 7.
ANOVA for factors- dependent- Tensile strength

Source	DF	Adj. SS	Adj. MS	F. Value	P. Value
Compactability%	1	0.013520	0.013520	15.83	0.002
Mixing Time (min)	1	0.007605	0.007605	8.90	0.011
Bentonite%	1	0.001125	0.001125	1.32	0.273

Tensile strength Regression Equation (N/cm^2) = 0.0850
+ 0.02600 Compactability % + 0.01950 Mixing Time (min)
+ 0.00750 Bentonite % (3)

Table 8.
Comparison between used methods for determining Tensile strength

Evaluation method	Compactability %	Mixing Time (min)	Bentonite %	Tensile strength (N/cm^2)
Predication	4	4	4	0.297
Practical	4	4	1	0.33
Regression	4	4	1	0.291

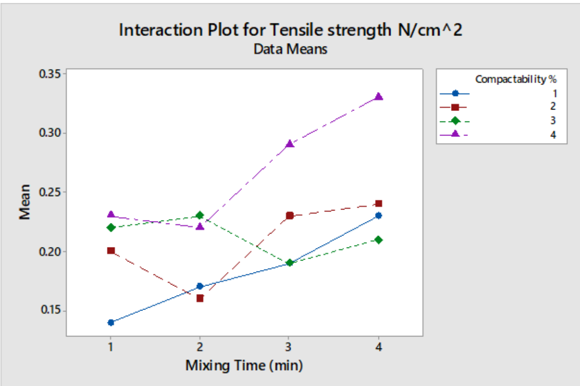

Fig. 10. Interaction plot of compactability and mixing time for tensile strength

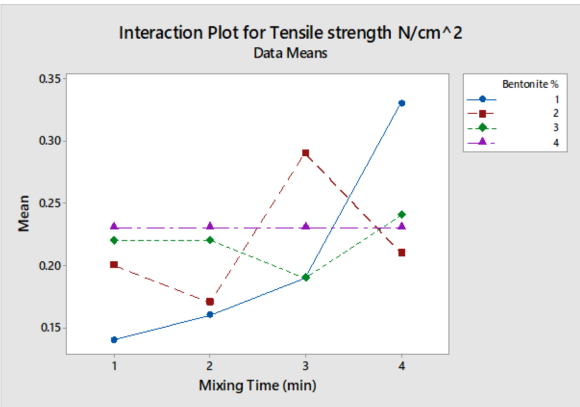

Fig. 11. Interaction plot of bentonite and mixing time for tensile strength

5. Conclusions

The results suggest that the properties of green sand can be influenced by various factors such as compactability, bentonite content, and mixing time. By adjusting these factors, it may be possible to produce green sand with specific properties that are suitable for different applications. The study has identified specific combinations of moulding parameters that can have a significant impact on permeability, tensile strength and compressive strength of the green sand.

A statistical analysis of data showed that there is a simultaneous increase in permeability, tensile strength and compressive strength of green sand when the moulding parameters are increased, and vice versa. The study found that the highest value of permeability was achieved when a combination of 49% compactability, 11% bentonite, and 2 seconds of mixing time was used. The study also found that a combination of 34% compactability, 7% bentonite, and 4 seconds of mixing time resulted in the lowest value of permeability for the green sand, with a value of 84.
The interaction of 39% compactability, 11% of bentonite, and 6 seconds of mixing time gave the highest value of compressive strength, which was 17.67 N/cm^2. Additionally, the combination of 34% compactability, 5% of bentonite, and 2 seconds of the mixing time resulted in the lowest value of compressive strength, which was 9.32 N/cm^2.

The highest tensile strength 0.33 N/cm^2 was achieved when the compactability was 49%, the bentonite content was 5%, and the mixing time was 8 seconds. Conversely, the lowest tensile strength 0.14 N/cm^2 was observed when the compactability was 34%, the bentonite content was 5%, and the mixing time was 2 seconds. There is good agreement between the experimental results, statistical predictions, and regression analysis. This suggests that the study was well-designed and that the results are reliable.

Conflict of interest

The author declare that he has no conflict of interest.

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