

# **Application of Tagushi Design in Quality Improvement for Construction Industry**

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## **Abstract**

This study aims to utilize Tagushi design in quality improvement for construction industry. A comparison between full factorial and Tagushi design is conducted experimentally. The experiment investigates the effect of four major factors and their interactions on concrete compression strength. The factors are; percentage of recycled aggregates, percentage of dune sand, amount of steel fiber in concrete mixture and test time. Two types of design of experiments (DOE) have been done to test different concrete mixtures by using different combinations of the mentioned four factors. The collected data has been studied using full factorial and Taguchi “Robust” designs. Also, Minitab software results have been obtained and analyzed. Based on full factorial design, it was found that all factors were significant, whereas the interactions between factors were significant only for two-way interaction. The three-way and four-way interactions were insignificant. On the other hand, Taguchi analysis was used to determine the main effects of factors. The results of both full factorial and Taguchi methods were the same except for the percentage of dune sand. In the full factorial method, when combining both types of sand, the compressive strength of concrete increased. In contrast, Taguchi showed opposites results.

## **Keywords**

Design of Experiments, Full factorial, Taguchi design, construction industry

## **Introduction and Literature review**

Concrete is the main building material that is widely used in all kinds of civil engineering works like substructure, infrastructure, buildings, installations of defense work, environs defense and local-domestic improvements. Basically, concrete is made by three basic components which are water, natural aggregates, such as sand, rocks or gravel, and Portland cement. Recently, the perception of the continued extensive abstraction and use of natural resources aggregates is questioned at a worldwide level (Lawson et al, 2001). In order to overcome this problem and decrease the rapid consumption of natural aggregates, concrete debris, resulted from demolition works, are being recycled and used in concrete productions. Recycled concrete aggregate lessens impact on landfills, reduces energy depletion and provides cost reserves (Huang et al, 2002).

Yehia et al. (2015) studied the concrete properties produced with 100% replacement of recycled aggregates (RA). The test results showed that compressive strength of the 100% RA concrete could be achieved with high packing density of concrete” high compaction”. Zhou and Chen (2017) studied the effect of two different types of recycled aggregate in the mechanical properties of concrete. The results showed different mechanical properties for various types of recycled aggregates. RPA had lower water absorption and density than RCRA. Therefore, RPA concrete had high compressive strength than RCRA. The compressive strength of recycled aggregate concrete was similar and sometimes higher than that of normal aggregate concrete. The authors referred this result due to high absorption of recycled which lead to higher bonding strength between cement and aggregate. M. Baena et al. (2016) studied the effect of recycled aggregate on concrete mix. Test results showed C20 compressive strength decreased regardless of the percentage replacement of recycled aggregate due to different in water-cement ratio. C30 for 50% and less

replacement, the compressive strength increased, but for more than 50% replacement it decreased due failure occurred through aggregate. C50 at 20% replacement increased and for more than that it will start to decrease.

Gao et al. (2017) studied the experimental results relevant to the compressive behavior of Steel Fiber Reinforced Recycled Aggregate Concrete (SFRAC). Test results showed that the reinforcing effects of SFs on RA concrete was greater than NA concrete. The combined effect of SFs and RA increased the compressive strength of concrete considerably, but it couldn't reach to NA concrete strength. Carneiro et al. (2014) examined the compressive behavior of steel fiber (SF) recycled aggregate (RA) concrete. It was reported that the addition of SF increased the compressive strength up to 20%.

To date, no study on the effects of using dune (desert) sand on the compressive strength of concrete has been reported. Furthermore, few studies conducted statistical analysis on the effect of both recycled aggregate and steel fiber on concrete mix. This study aims at investigating the influence of four factors in combination; recycled aggregate, dune sand, steel fiber, and test time on a concrete mix experimentally and statistically. This combination will be investigated for the first time, no single study has included the effect of these four factors on one concrete mixture. The outcome of this research will assist civil engineers by providing them with guidelines needed for designing economical and sustained concrete

## Methodology

The main objectives of the experimental program were to investigate variability of four factors (dune sand %, recycled aggregate %, steel fiber dosage, and test time) and their impact on concrete production. In other words, this research project will evaluate the properties of concrete prepared with 0, 50 and 100 % recycled aggregate and compared with those of 100 % natural aggregate. In addition, three different percentages of dune sands; 0, 50 and 100% will be used. Also, different steel fiber dosage will be used in different mixes; 0, 1.5 and 3% of concrete total volume. Finally, each mix was tested at different periods; 3, 7, and 28 days.

### Materials:

- The recycled aggregate was obtained from Al Dhafra recycling plant in Abu Dhabi with maximum size of 25 mm. However, two grades of normal aggregate were used (maximum size of 19 mm and maximum size of 10 mm). Normal aggregates and normal sand “crushed gravel” were collected from Stevin Rock quarry in Ras Al Khaima. In addition to that, dune sand “desert sand” was used with a maximum size of 2.36 mm and obtained from Al Ain municipality. Figure 1 shows the used material of sand
- Steel fibers used in this study were hooked at both ends with a length of 30 mm, a diameter of 0.55 mm, and yield stress of 1100 MPa.
- 53 grade ordinary Portland cement conforming to IS:12269-1987 standard with a 28-days compressive strength of 35 MPa. Tap water was used for mixing and curing.

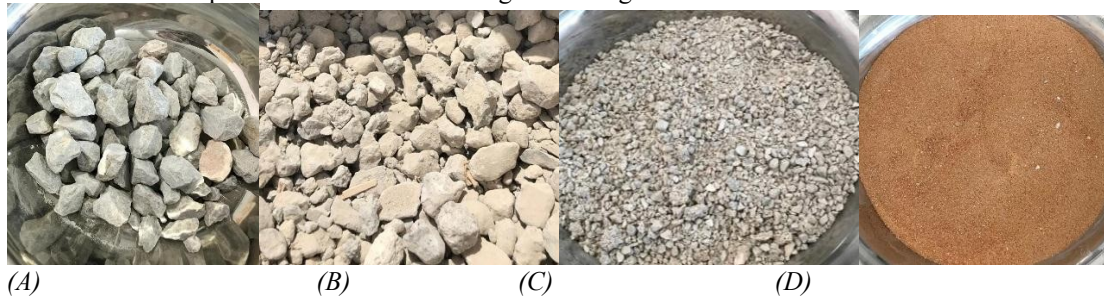


Figure 1: (A) manufactured aggregates, (B) recycled aggregates, (C) manufactured sand and (D) is Dune/desert sand.

### Equipment and Test procedures

The influence of recycled concrete aggregate on properties of concrete was done by performing compressive tests at 3, 7, and 28 days. The compressive test performed using Compression testing machine.

ACI 211.1 mix design method was used to determine the proportions of the mixes. Different concrete mixes have been done to achieve the target compressive strength which should ranges between 30 to 35 MPa. The steps of concrete mixing, casting, and testing are summarized As follows:

First: prepare cylindrical molds,

Second: Mixing concrete proportion

Third: Casting concrete in the cylindrical molds, and cover it with plastic sheet  
Fourth: curing for the specified time  
Fifth: sample preparation for testing  
Sixth: conduct compression test.

## Design of Experiment (DOE)

After comprehensive study of the literature review, the following list of factors and their levels were considered for the experiment. These factors are displayed in Table 1 and explained in more details below. The response factor of interest in the first set of experiments is the compressive strength of concrete mixture.

There are four main factors to be considered in this experiment as described above. Each of the factors has three levels. Hence, a full factorial design and Taguchi design are chosen for analyzing this experiment. Therefore, all the effects will be considered which involved the main factors and their interactions; second order, third order and fourth order.

Table 1: factors and their levels considered in this experiment.

Factors	Number of Levels	Level 1	Level 2	Level 3
Percentage of Recycled Aggregate	3	0%	50%	100%
Percentage of Dune Sand	3	0%	50%	100%
Steel Fiber dosage	3	0%	1.5%	3%
Test Time	3	3 days	7 days	28 days

In order to confirm the results, three trials of the experiment were decided to be conducted. Therefore, full factorial design needs number of experiments equal to  $n_k = 34 = \mathbf{81}$  with three replicates which make a total of 243 runs need to be carried out. Whereas, Taguchi design needs number of experiments equal to  $[(n - 1)(k) + 1] = [(3 - 1)(4) + 1] = \mathbf{9}$  with three replicates which make a total of only 27 runs need to be carried out

## Statistical Model:

A statistical software package called Minitab, version 18, has been used to analyze the collected experimental data. The statistical model for the full factorial design is as follow:

$$y_{ijkl} = \mu + \alpha_i + \tau_j + \beta_k + \omega_l + (\alpha\tau)_{ij} + (\alpha\beta)_{ik} + (\alpha\omega)_{il} + (\tau\beta)_{jk} + (\tau\omega)_{jl} + (\beta\omega)_{kl} + (\alpha\tau\beta)_{ijk} + (\alpha\tau\omega)_{ijl} + (\alpha\beta\omega)_{ikl} + (\tau\beta\omega)_{jkl} + (\alpha\tau\beta\omega)_{ijkl} + \epsilon_{ijkl}$$

where  $y_{ijkl}$  is the concrete compressive strength,  $\mu$  is the overall mean,  $\alpha_i$  is the effect of recycled aggregate,  $\tau_j$  is the effect of dune sand,  $\beta_k$  is the effect of steel fiber amount,  $\omega_l$  is the effect of test period,  $\epsilon_{ijkl}$  is the random error and all other terms are the interactions between the factors. The effect of all factors and interactions were tested to define the significant factors and interactions that affect the concrete compressive strength.

Test of Hypothesis: The following are hypothesis testing for model factors.

### Recycled Aggregate percentage:

Test whether the effect of recycled aggregates with 0%, 50% and 100% are the same on concrete compressive strength or each has a different effect.

$$H_0: \alpha_{0\%} = \alpha_{50\%} = \alpha_{100\%}$$

H1: at least one treatment effect is different Here, the  $\alpha$ 's represents the treatment effect

### Dune Sand percentage:

Test whether the effect of dune sand with 0%, 50% and 100% are the same on concrete compressive strength or each has a different effect.

$$H_0: \tau_{0\%} = \tau_{50\%} = \tau_{100\%}$$

H1: at least one treatment effect is different Here, the  $\tau$ 's represents the treatment effect.

### Amount of steel fiber:

Test whether the effect of steel fiber with 0%, 1.5% and 3% are the same on concrete compressive strength or each has a different effect.

H0:  $\beta_0\% = \beta_1.5\% = \beta_3\%$

H1: at least one treatment effect is different Here, the  $\beta$ 's represents the treatment effect.

Test Time:

Test whether the concrete compressive strength is increased with time. H0:  $\omega_3\text{days} = \omega_7\text{days} = \omega_{28}\text{days}$

H1: at least one treatment effect is different Here, the  $\omega$ 's represents the treatment effect.

Time is usually not a factor, but in this study particularly it was set as a factor to check whether our new concrete combinations have the same effect on time compared with the effect of the conventional concrete combinations described in the ASTM standard. However, the concrete compressive strength should increase with time.

**Note:** A significant level ( $\alpha$ ) of 0.05 is going to be used in all the report.

## Full Factorial Design:

In this section, a complete full factorial analysis will be conducted for our collected experimental data in order to distinguish between the significant and insignificant factors and their interactions on our response which is the concrete compressive strength.

## Main effect plot

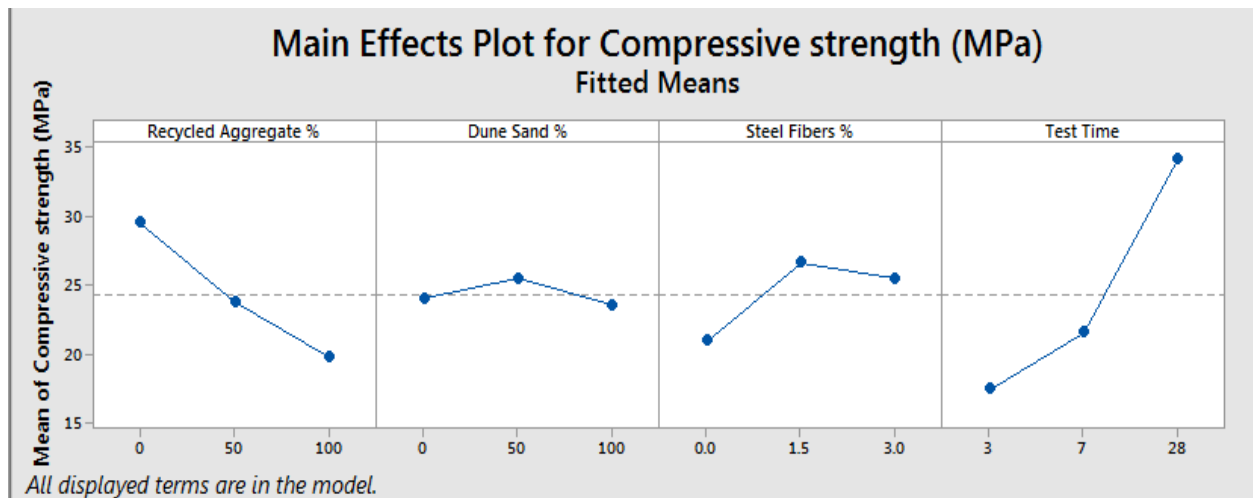
The main effect plot is useful to understand the main effect of each factor on the response as well as the effect of each individual level. The main effect plots are shown in Figure 2. It shows that the effect of both the percentage of recycled aggregate and test time are highly effective. The compressive strength decreases with increasing the percentage of recycled aggregates. Whereas, the compressive strength of concrete increases with time.

The effect of dune sand was very interesting. Replacing 100% of the manufactured sand with dune sand showed that the compressive strength has not changed. However, it is noticeable that using the combination of both types of sand has improved the compressive strength of the concrete. When combining both types of sand, the voids between the sand particles will be reduced which will result in a more compacted concrete.

The inclusion of steel fibers by 1.5% to the concrete mix improved the compressive strength by almost 30%.

Unexpectedly, when 3% of steel fiber was added the compressive strength increased by only 19%. This result could be due to the loss of workability and homogeneity of the concrete mix when adding 3% of steel fibers.

*Figure 2: Main effects plots – Full factorial*



## Taguchi Design:

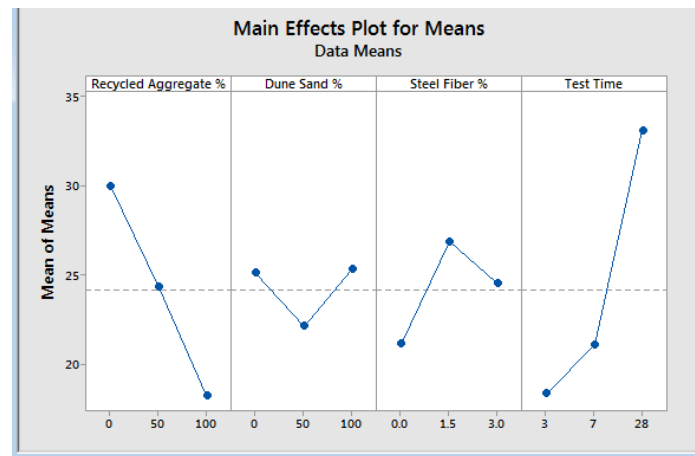
In this section, Taguchi analysis will be conducted for our collected experimental data in order to study the main effects of each factor and their levels. However, Taguchi design does not cover the effect of factor interactions.

The main effect plot is shown in Figure 3. The figure shows that the compressive strength decreases with increasing the percentage of recycled aggregates. Whereas, the compressive strength of concrete has a proportional relationship with time.

Using 100 % dune sand in the mix didn't change the compressive strength compared to 100

% manufactured sand. However, it is noticeable that using the combination of both types of sand has decreased the compressive strength of the concrete.

The addition of steel fibers by 1.5% and 3% to the concrete mix improved the compressive strength. Unpredictably, the addition of 3% steel fiber has less effect than that of 1.5%. This result could be due to the loss of workability and homogeneity of the concrete mix when adding 3% of steel fibers.



*Figure 3: Main effects plot for means – Taguchi Design*

### **Results discussion and comparison between the results of full factorial and Taguchi Designs:**

Full factorial and Taguchi methods are methodology for systematically applying statistics to experimentation. Both methods cover the main effect of factors. However, the full factorial can find the interaction effect of factors while Taguchi can't. Moreover, the number of experiments in full factorial method is much higher than that of Taguchi. Therefore, full factorial method is more accurate and complex than Taguchi method.

In our study, the results of the main effect plots for both methods were the same except for the percentage of dune sand. In the full factorial method, when combining both types of sand, the compressive strength of concrete increased. In contrast, Taguchi showed opposites results.

### **Conclusion**

Concrete compressive strength has been studied in this report. Four factors of interest were defined and varied throughout the experiment in order to study their effects on the target response, i.e. compression strength. The factors are percentage of recycled aggregate, percentage of dune sand, amount of steel fiber and test period. The full factorial design was used and found to be valid via testing data normality and equal variance. Then the results showed that all four factors and the two-way interactions were significant. The insignificants were the three- and four-way interactions. The model equation has been refined by taken out the insignificant factors and interactions. It was found that the R-Squared is high with value of 94.93% which means that our model is valid. After that, the response optimizer tool via Minitab was used to determine the optimal factors combination to obtain our target-quality concrete mixture. A high-quality concrete mixture with a compression strength of 35 MPa can be attained when using 50% replacement of recycled aggregate, 100% replacement of dune sand and only 1.5 % inclusion of steel fiber, then keeping the mixture to gain full strength for 28 days. After that, The Taguchi method was used to determine the main effects of factors. The results of both methods were the same except for the percentage of dune sand. In the full factorial method, when combining both types of sand, the compressive strength of concrete increased. In contrast, Taguchi showed opposites results.

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