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# Fuzzy logic model for the prediction of concrete compressive strength by incorporating green foundry sand

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**Abstract.** This work is conducted with the aim of using waste material to reserve the natural resources. The objective is accomplished by conducting experimentation and verify by modeling based on fuzzy logic. In experimentation, concrete is casted by using natural/river sand as fine aggregate and termed as control specimen. Natural sand is conserved by replacing it with used foundry sand (UFS) by an amount of 10, 20 and 30% by weight. Fresh and hardened properties of concrete are investigated at different ages. It is observed that compressive strength and modulus of elasticity reduced with the increase in amount of UFS. Furthermore, concrete compressive strength is predicted by using fuzzy logic model and verified at different replacement ratio and age with experimental observations.

**Keywords:** conservation; natural river sand; used foundry sand; compressive strength; fuzzy logic model

## 1. Introduction

Concrete is used as structural and non-structural material from centuries. Concrete is also termed as largest man made material in this world. Lot of energy and natural resources are required to get its constituents like; coarse and fine aggregates, water and cement. All used resources are natural and non-renewable and their demand has significantly increased with time. Rehablitation, conservation and strengthening of concrete structures are now important areas of research for consevation of natural resources (Rashid *et al.* 2015, 2016). Efforts are made by researchers to manage the waste in concrete instead of using in landfill to conserve the natural resources and energy (Siddique 2007, 2009, Rashid *et al.* 2016).

Foundry sand is high quality sand which is rich in silica. It is a by-product of ferrous and non-ferrous industries. It has uniform physical and chemical characteristics and good thermal conductivity and that it is also one of the reason that it can be exposed to high temperture like 1500℃ in foundries (Basar and Aksoy 2012). After using several times, foundry sand loses its characteristics then it is treated by adding binders or additive and reused. But after crossing its threshold values it cannot be used further and discarded and termed as used foundry sand (UFS) (Siddique 2009, Siddique *et al*. 2011). The metal casting process and extraction of UFS are mentioned in Fig. 1. Due to several types of metal casting (ferrous or non-ferrous), different types of binders, diffenrent types of furnaces and different types of finishing processes, properties of foundry sands vary significantly (Singh and Siddique 2012a, b). More specifically, with respect to binders, foundry sands are classfied as green foundry sand (GFS) and chemical bonded sand (Etxeberria *et al.* 2010). GFS is generally black or grey in color due to high concentration of carbon and clay in it (Siddique 2009, Siddique and Noumowe 2008).

American foundry society conducted a survey on beneficial reuse of UFS and reported that about 55% of foundry sand is reused in construction fill and in concrete (Fig. 2) (Beneficial use of secondary material 2008). Along with concrete and construction other potential usages of UFS are mentioned in Fig. 2. With combination of other constituent of concrete UFS is effective to reduce the cost for production and for user. Utilization of UFS is not only cost effective but also favorable from environment point of view. For example large quantity of processed earth is consumed in earthwork projects which results increase in cost and harmful for the environment. But, by uisng GFS both parameters can easily be incorporated. Friction angle of GFS is found to be superior to silt, clay or dirty sand. So, it is prefferable to use for embakment fills due to its higher shear strength propoerties. Applications of GFS are further extended and used as base coarse, bedding for the sewer pipes, slope stability, structural backfill, embankment etc (Beneficial Use of Secondary Material 2008, Siddique 2007).

Its utlization is dependent on the target strength which must be achieved to fulfill the required purpose. Different amounts of UFS is used to select the appropriate strength (Basar and Aksoy 2012, Khatib *et al.* 2010). A large data base is availabe having different properties of concrete at various percentages of UFS (Siddique 2007). The physical and chemical propoerties of UFS varies from region to region and type of metal casting, which may influence the properties of concrete. In some cases the compressive

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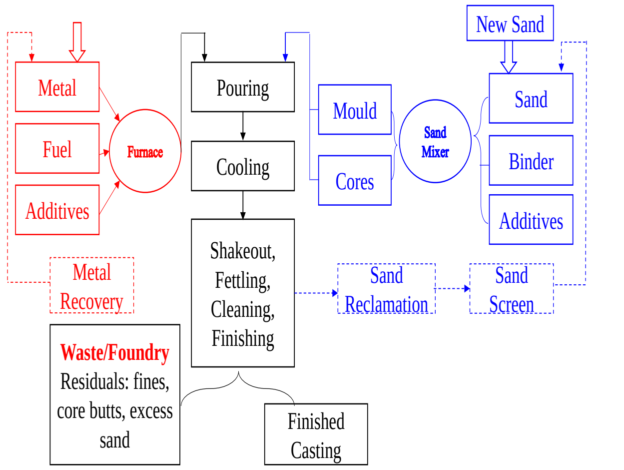



Fig. 1 Metal casting process and extraction of waste foundry sand

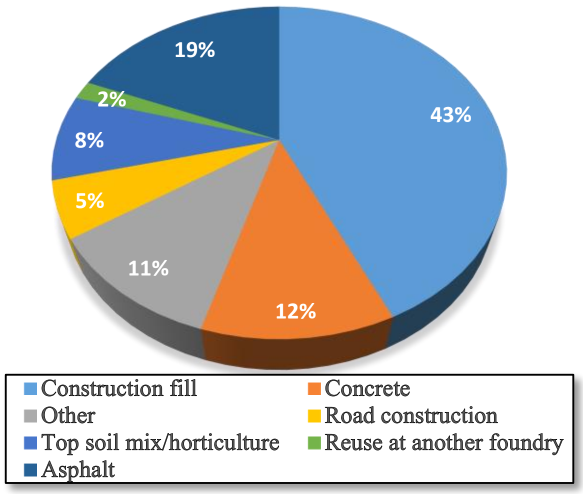



Fig. 2 Beneficial reuse of used foundry sand

Table 1 Properties of fine aggregates

| Property | Natural sand | Green foundry sand |
|---|---|---|
| Specific gravity | 2.76 | 2.48 |
| Moisture content (%) | 1.84 | 3.11 |
| Fineness modulus | 2.8 | 2.1 |

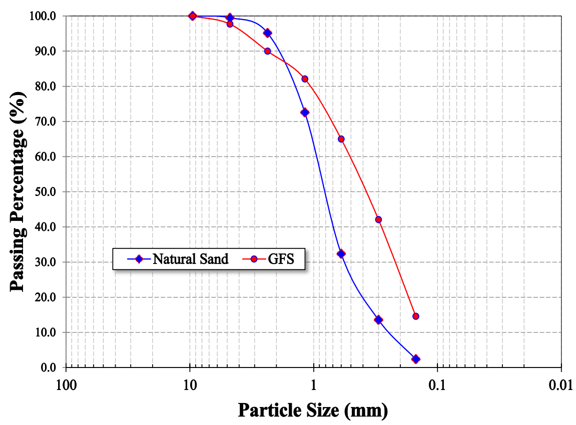



Fig. 3 Particle size distribution of both types of sand

strength of concrete is increased by increasing amount of UFS but in many cases compressive strength is reduced with the increase in amount of UFS. Similar trend is observed for flexural strength, tensile strength and modulus of elasticity of concrete having UFS (Basar and Aksoy 2012, Etxeberria *et al.* 2010, Monosi *et al.* 2010, Reddi *et al.* 1996, Siddique *et al.* 2011, Siddique *et al.* 2009, Siddique and Noumowe 2008, Singh and Siddique 2012b).

Compressive strength is the fundamnetal property of any concrete which is used in designing of any concrete strucutre. In authors point of view it must be predicted to save time, money, laboratory work and natural resources. Theoretical model, analytical modelling and numerical modelling are the tools for developing such model with some constraints (Fathi *et al.* 2015, Kar *et al.* 2016, Shelke and Gadve 2016). Often, human judgments are ambiguous, vague and cannot be estimated with exact numeric value, so the crisp values are not suitable to model real world situations. Zadeh (1965) proposed the concept of fuzzy set theory and successfully used it to handle imprecision to solve the ambiguity and vagueness in information from human judgment. Fuzzy sets have found several flourishing applications in various fields including control (Masumpoor and Khanesar 2015), robot selection (Rashid *et al.* 2014), intelligent systems (Chang *et al.* 2015), satellite image analysis (Al-Obeidat *et al.* 2015) and the list goes on. Finally, one of theroretical model is the fuzzy logic approach which is used in various applications of engineering especially in construction industry (Ross 2009, Tanyildizi 2009a, b, Topçu and Sarıdemir 2008).

With the aim of conservation of natural resources, efficient utilization of waste materials in construction industry and introducing a technique to evaluate the compressive strength of concrete with UFS. Detailed experimentation is conducted in which fine aggregate is replaced by adding GFS by weight. Fresh and hardened properties of concrete are investigated. Behavior of compressive strength is studied in detailed by measuring it at 7, 28 and 63 days of curing. And all values of compressive strength are verified by using fuzzy logic model. In which days and replacment of fine aggregate are used as input and obtained compressive strength is output.

## 2. Experimental description

The Experimental work is conducted by utilizing local materials. Foundry sand is also procured from locally available foundry. Detail of materials with their properties, specimen preparation and types of tests are explained in following sub-sections.

### *2.1 Materials*

Locally available aggregates, both fine and coarse, and ordinary Portland cement are used in this experimentation. Another type of fine aggregate is GFS that procured from local industry. There are clumps of GFS and it is crushed before use in concrete and for examining its properties. Bentonite clay is used as binder in GFS. Properties of both fine aggregates are investigated in detail to make an appropriate comparison which may be used for other type

Table 2 Summary of test and number of specimens for evaluating hardened properties of concrete

| Mixture | w/c* | UFS % | Modulus of elasticity | Compressive strength | | | Acronyms |
|---|---|---|---|---|---|---|---|
| | | | | 7 Days | 28 Days | 63 Days | |
| Control | 0.6 | ----- | 3 | 3 | 3 | 3 | NS** |
| | 0.6 | 10 | 3 | 3 | 3 | 3 | BC***-10 |
| GFS | 0.6 | 20 | 3 | 3 | 3 | 3 | BC-20 |
| | 0.6 | 30 | 3 | 3 | 3 | 3 | BC-30 |

w/c*=water to cement ratio, NS**=Natural sand, BC***=Bentonite clay

of sands. Specific gravity, moisture content and sieve analysis are conducted and results are showed in Table 1. It is clear from the Table 1 that GFS is finer than natural sand and particle size distribution is also drawn for both types of sand that verifies the fineness of GFS as compared to natural sand (Fig. 3). ASTM C-33 defines the range of fineness modulus which is applicable for use in concrete and its range is 2.3 to 3.1. And observed value for GFS is slightly less than the limits. But, it is considered as acceptable due to mixing with the natural sand.

### *2.2 Specimen preparation and testing*

Four concrete mixtures are prepared by incorporating ordinary Portland cement, fine aggregate and gravel, all constituents are mixed with a constant water to cement ratio of 0.6. Mixture proportion is 1:2:4. One mixture with 100% natural sand is termed as control mixture, while other three mixtures have different amount of GFS. The replacement of natural sand with GFS are 10, 20 and 30% by weight to prepare three mixtures, respectively. No admixture or plasticizer is used in this work. Concrete cubes of size 150 mm and cylinder of 150×300 mm are casted to evaluate the compressive strength and modulus of elasticity, respectively.

## 3. Results and data discussion

In this section, experimental observations regarding the properties of fresh and hardened concrete has been discussed. Section is divided into three sub-sections to discuss the properties in precise an appropriate way.

### *3.1 Workability*

Workability of concrete is measured by slump test and compacting factor test. It is observed that workability highly depends upon the binder used in foundry sand. Slump value is increased by using chemical binder and is reduced by using bentonite clay as binder (Etxeberria *et al.* 2010). Water to cement ratio demand is increased by using foundry sand and at similar water to cement ratio workability is reduced with the increase in replacement level (Siddique *et al.* 2009). The reason for reduction in workability is presence of clay in the form of bentonite clay, which have the ability to absorb significant amount of

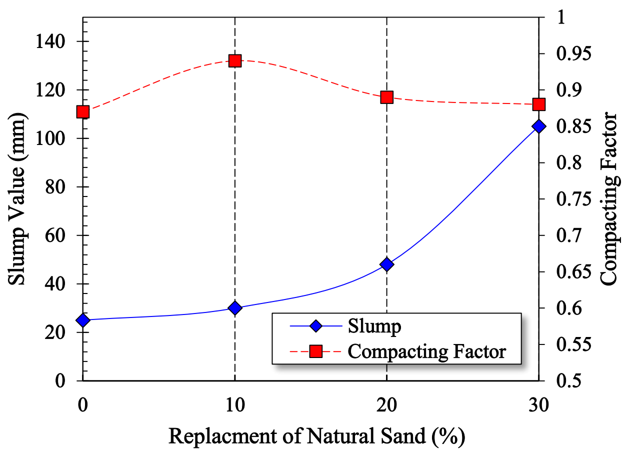
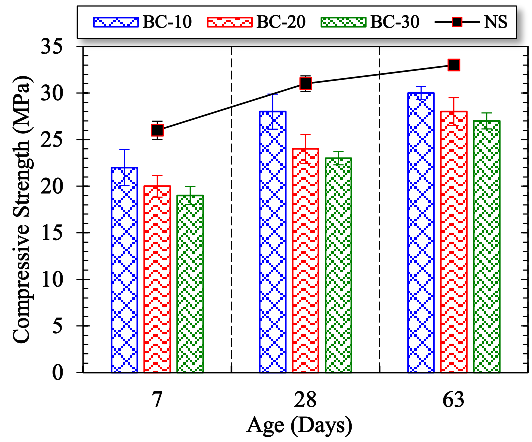
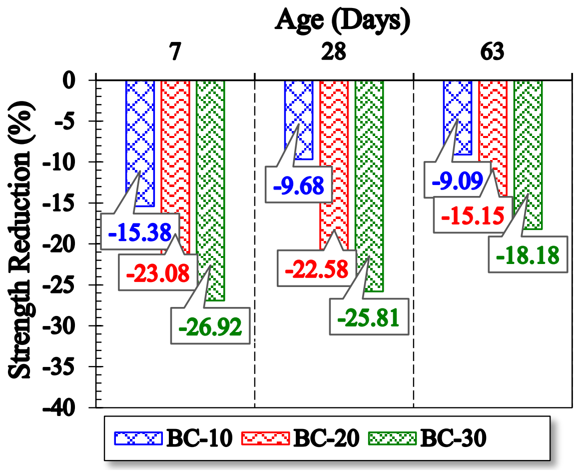



Fig. 4 Influence of green foundry sand (GFS) on workability of concrete




(a) Influence of age




(b) Percentage reduction in strength

Fig. 5 Influence of age and GFS on compressive strength of concrete

moisture as compared to other binders. And ultimately this absorption of moisture is resulted in the reduction of fluidity of concrete.

Here, two methods are used to verify the influence of foundry sand on workability of concrete as shown in Fig. 4. At 10% replacement level, slump values and compacting factor are increased marginally due to presence of

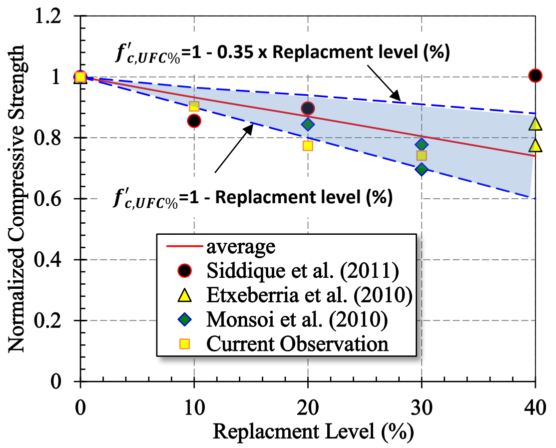



Fig. 6 Data base of compressive strength of concrete at different replacement of NS by UFS

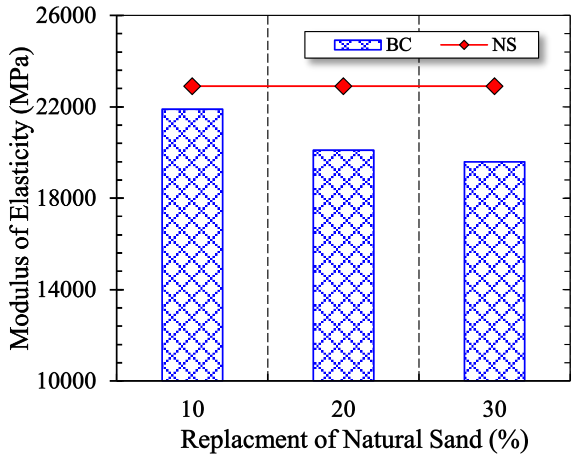



Fig. 7 Influence of foundry sand on modulus of elasticity (E) of concrete

round/smooth shape of fine aggregate. But with further increment in replacement compacting factor is reduced which is according to the available literature (Etxeberria *et al.* 2010, Siddique *et al.* 2009). Slump values are slightly increase at 20% replacement and significantly increase at 30% and may be excluded and only consider compacting factor values for such replacement. Super plasticizer or admixtures are used to increase the fluidity of concrete having foundry sand as fine aggregate (Siddique *et al.* 2009).

### 3.2 Compressive strength

Fig. 5(a) presents the compressive strength of concrete at age of 7, 28 and 63 days. Compressive strength increases with the increase in age. Rapid increase in compressive strength is observed at 28 days of curing age as compared to 7 days compressive strength, further increase in compressive strength is observed with further increase in age but at different rate. Increase of 19% and 27% in compressive strength is observed with reference of 7 days compressive strength of control specimen. Similar trend is observed for the rest of the specimens, which have different replacement ratios. In case of 10% replacement of natural sand by GFS, 7% increase in compressive strength is observed after 63 days when it is compared with the 28 days age. In case of 20% and 30% replacement, the increase in compressive strength from 28 days to 63 days, is 17%. Which is higher than 10% replacement case. However, the compressive strength is lower than control specimen.

Another aspect of Fig. 5(a) is presented in Fig. 5(b), which presents the decreasing trend of compressive strengths. It is clear from Fig. 5(a) that compressive strength decreases with the increase in percentage replacement of natural sand by foundry sand. At each age reduction in compressive strength with respect to control specimen is presented in Fig. 5(b). Maximum reduction in compressive strength is 26.92% and it is observed at age of 7 days, when natural sand is replaced by an amount of 30% by foundry sand. Minimum reduction is observed after 63 days of age and these amount are 9.09%, 15.15% and 18.18%, for 10%, 20% and 30% replacement level, respectively.

Compressive strength of concrete specimens is reduced with the increase in the amount of UFS due to following reasons; (i) Higher surface area of fine particles which results in the reduction of water cement gel in matrix (Basar and Aksoy 2012, Khatib *et al.* 2010, Khatib and Ellis 2001, Monosi *et al.* 2010, Reddi *et al.* 1996, Siddique *et al.* 2011). Due to this reason, higher amount of water is required to fulfill the workability requirement as mentioned in Fig. 4. (ii) Weak interaction of cement paste and aggregate due to presence of fine aggregate, which results in the weak interfacial transition zone (Mehta 1986). After small application of load crack may appear at interfacial transition zone. (iii) Presence of binder in UFS highly influence the mechanical properties of concrete (Monosi *et al.* 2010, Reddi *et al.* 1996, Siddique *et al.* 2011). Binder loses the contact between aggregate and matrix. (iv) Presence of carbon or clay (as binder) in GFS is responsible in delaying in compressive strength achievement and may be equal to the control specimen if it is cured for more than three months (Monosi *et al.* 2010). (v) Presence of clay may results in the moisture absorption and increase in moisture absorption leads to the reduction in compressive strength (Basar and Aksoy 2012). (vi) Similar trend of reduction in compressive strength is observed in several studies (Fig. 6) (Khatib *et al.* 2010, Khatib and Ellis 2001, Monosi *et al.* 2010, Reddi *et al.* 1996).

It is clear from Fig. 6 that compressive strength is reduced with the increase in replacement level. This comparison is made after 28 days of standard curing which is mostly reported and used in designing of concrete structures. Some contradictions are observed among researchers, few studies are reported the increase in compressive strength with the replacement level (Siddique *et al.* 2011, Siddique *et al.* 2009, Singh and Siddique 2012a, b). Whereas, many researchers are agreed on reduction in compressive strength with the increase in replacement level of fine aggregate with foundry sand (Basar and Aksoy 2012, Etxeberria *et al.* 2010, Khatib *et al.* 2010, Khatib and Ellis 2001). This contradiction is mainly due to presence of type of foundry sand and more specifically the additive or binder present in the foundry sand. Here, the focus is on the reduction in the

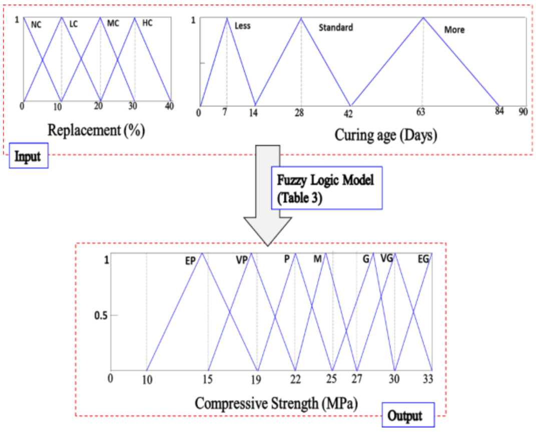



Fig. 8 Block diagram used for fuzzy modeling

compressive strength which may leads to the early deterioration, reduction in intended service life, crushing of concrete failure etc. So detailed investigation is conducted with respect to reduction in compressive strength.

In Fig. 6, two limits are made with respect to the replacement level up to 40%. Authors and other researchers' data lies within these limits and average line is also drawn in Fig. 6. Trend for reduction in strength is linear and it is reduced by an amount of 26% at 40% replacement with minimum 12% and maximum 40% variation. For the minimum and maximum lines, respective equations are also presented in Fig. 6.

### *3.3 Modulus of elasticity*

Similar trend, which is observed in compressive strength by incorporating foundry sand, is observed in modulus of elasticity after 28 days of curing. Fig. 7 presents the modulus of elasticity of concrete with zero foundry sand and up to 30% replacement level. Reduction of 4.37, 12.23 and 14.41% is observed in modulus of elasticity of concrete with replacement level of 10, 20 and 30%, respectively, as compared to the control specimen. The variation in modulus of elasticity between 20 to 30% is less as compared to 10 to 20% or 10 to 30%. Reduction of 8.22 percent is observed by increasing replacement from 10 to 20% and further reduced by an amount of 10.50% at 30% replacement, when comparison is made with the case of 10% replacement. Only 2.49% reduction in modulus of elasticity is observed when comparison is made between 20% replacement to 30% replacement level. Similar reason for the reduction in the compressive strength of concrete with foundry sand may attributed towards the reduction in modulus of elasticity. Several empirical relationships are also available which verify that modulus of elasticity is the function of compressive strength. That might be used to evaluate the modulus of elasticity at concerned age. Mostly 28 days compressive strength and modulus of elasticity are reported so, only 28 day modulus of elasticity test is conducted and reported here.

## 4. Fuzzy logic model for prediction of compressive strength

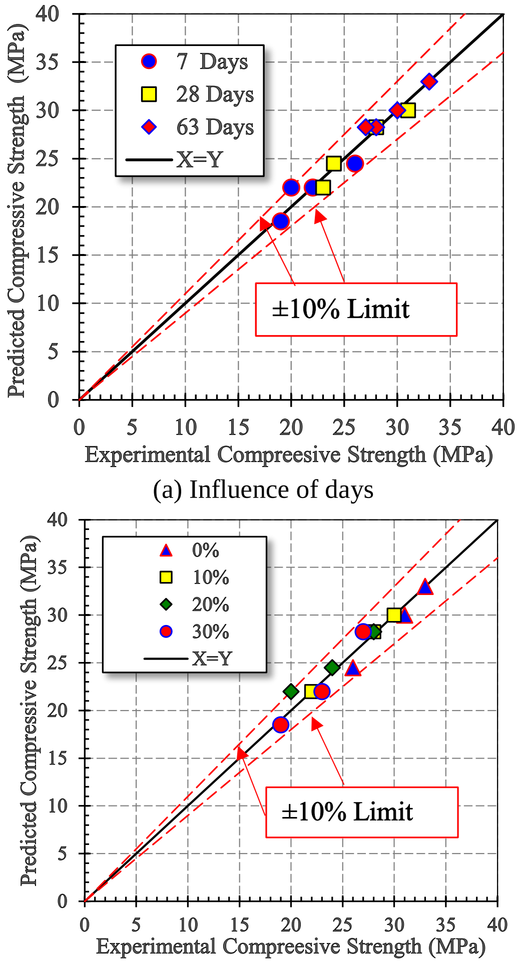



Fig. 9 Comparison of experimental versus predicted compressive strength

Fuzzy logic approach is used to predict the compressive strength of concrete at various days and at different replacement percentages of GFS. Following sub-sections demonstrate the mechanism of model and verification with experimental observations.

### *4.1 Algorithm for fuzzy logic*

Fuzzy set theory has developed five decades earlier and successfully used in various engineering applications (Ross 2009). Here, fuzzy logic model is developed to predict the compressive strength of concrete having UFS. For this purpose, authors have to use fuzzy implication to define the rule base model between input and output values. A fuzzy implication "$I$" is a binary operation on (0,1) with order reversing first partial mappings and order preserving second partial mappings such that: $I(0,1)=I(0,0)=I(1,1)=I(1,0)=0$ (Shi *et al*. 2007). Fig. 8 shows the block diagram of fuzzy logic model. All notations used in Fig. 8, are presented in Table 3. Two parameters are used as input and result one output (compressive strength). Inputs are curing age in days and replacement of fine aggregate by UFS in percentage (Fig. 8). Two inputs are fuzzified and fuzzy rules are proposed based on previous literature and current

Table 3 Rule base table for fuzzy logic model

| | No Change (NC) | Low Change (LC) | Medium Change (MC) | High Change (HC) |
|---|---|---|---|---|
| Less | Medium (M) | Poor (P) | Poor (P) | Very Poor (VP) |
| Standard | Very Good (VG) | Good (G) | Medium (M) | Poor (P) |
| More | Extremely Good (EG) | Very Good (VG) | Good (G) | Good (G) |

experimental observation to obtain the goal. The model rules are written in Table 3. For example; IF days are standard curing age and replacement is high THEN compressive strength is poor. Alternatively model is made by using one of the fuzzy implicator in Eq. (1) to predict the compressive strength (Ross 2009), which is defined as

$$I(x,y) = \begin{cases} 1 & \text{if } (x \le y); \\ y & otherwise, \end{cases} \tag{1}$$

### 4.2 Verification of model

Proposed model is verified by comparing predicted compressive strength by experimental compressive strength (Fig. 9). Fig. 9(a) shows the influence of age and it is observed that compressive strength is increased with the increase in curing age and also verified by predicted values. All data lies strictly within ±10% limit, which ensure the applicability of the proposed model and may be used for more days. Fig. 9(b) shows the influence of percentage replacement of fine aggregate with UFS and it is observed that the control specimen have higher compressive strength as compared to other specimens. With the increase in percentage of UFS the compressive strength is reduced and all experimental observations are verified by proposed model. No data point lies beyond the limit of ±10%, which verify the applicability of proposed model. Ratio of compressive strength between experimental and predicted value is 0.999 with standard deviation of 0.041.

## 5. Conclusions

Used foundry sand is incorporated in concrete by replacing fine aggregate with different amount. Workability, compressive strength and modulus of elasticity are observed experimentally and compressive strength is predicted by using fuzzy logic model. By experimentation and modeling following conclusions are extracted;

• The Workability, compressive strength and modulus of elasticity are reduced with the increase in amount of used foundry sand.

• Compressive strength is increased with the increase in age of curing irrespective of the replacement ratio.

• Compressive strength is verified by predicting it by using fuzzy logic approach. Close resemblance was observed between experimental and predicted values.

Large data about UFS in concrete is available in literature and this proposed model may extended to incorporate all parameters. Because properties of UFS vary significantly with the type of binder. The authors are working on other types of binder and will extend this model by incorporating available literature.

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