

# Application of multi-hybrid metaheuristic algorithm on prediction of split-tensile strength of shear connectors

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**Abstract.** Shear connectors play a major role in the development of composite steel concrete systems. The behavior of shear connectors is usually calculated by push-out measurements. These experiments are expensive and take a lot of time. Soft Computation (SC) may be applied as an additional solution to remove the need for push-out testing. The objective of the research is to explore the implementation, as sub-branches of the SC approaches, of artificial intelligence (AI) techniques for the prediction of advanced C-shaped shear connectors. To this end, multiple push-out tests on these connectors will be carried out and the requisite data is obtained for the AI models. The Grey Wolf Optimizer algorithm (GWO) is built to define the parameters that influence the shear strength of angle connectors. Two regression metrics as determination coefficient ( $R^2$ ) and root mean square (RMSE) were used to measure the results of model. Furthermore, only four parameters in the predictive models are sufficient to provide an extremely precise prediction. It was found that GWO is a faster method and is able to achieve marginally higher output indices than in experiments.

**Keywords:** multi-hybrid metaheuristic algorithm; prediction; shear connector; split-tensile strength

## 1. Introduction

Shear connector is an important element for a composite member of steel concrete. The presence of a shear connector restricts the shear flow of the interface between steel and concrete (Shariati *et al.* 2011d, Shah *et al.* 2015, Ziaei-Nia *et al.* 2018). There are various types of shear connectors introduced and examined in recent years (Shariati *et al.* 2011a, 2014b, Khorramian *et al.* 2015, Paknahad *et al.* 2018). A review study was performed on different shear connectors by Shariati *et al.* (2012b). An experimental investigation was conducted by Shariati *et al.* (2016) to compare the performance of angle and channel shear connectors in high strength concrete (HSC). A series of push-out tests was performed by Shariati *et al.* (2012f) on channel shear connectors in HSC subjected to monotonic and fully reversed loading scenarios. They also evaluated the behavior of c-shaped and v-shaped angle connectors under different loading conditions (Shariati *et al.* 2012d, 2015). Choose the right shear connectors from a composite structure for the conversion of optimal shear strength (Sun

*et al.* 2019, Alam *et al.* 2020c, Li *et al.* 2020, Zhang *et al.* 2020). Compared to the other connectors, shear connector is smoother because standard sizes C-shaped shear connectors are available for hot iron steel profiles in most Steel shops (Zhang *et al.* 2019, Zhang and Wang 2019a, b, Mirsadeghi and Fanaie 2021). In addition, these types of connectors can be conveniently prepared by simply cutting their long steel profiles. The efficiency of a shear connector is based on many variables that control the interactive response of connector and surrounding concrete (Zhang 2014, Zhang and Ou 2015, Sun *et al.* 2018, Zhu *et al.* 2018). A key element in the construction of a Composite Member is the design resistance of a shear connector. The design value and design equations in standard codes are available. Currently, the specification code provides only for heading stud shear connectors and some kinds of shear connectors (Zhang *et al.* 2006, Zhang *et al.* 2010, Abedini and Zhang 2020, Abedini *et al.* 2020). The design strength of the shear connector is achieved by push-out test specimen. The majority of the research confirms that the shear connector capability and the shear link load slip behavior are equally significant (Hu *et al.* 2020c, Sun *et al.* 2020, Zheng *et al.* 2020, Xu *et al.* 2021). By means of the push-out test method, the performance of a L steel shear connector was tested by Kiyomiya and Yokota (1986). In their analysis, tensile shear connector fractures, concrete crush and

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concrete shear failures were found. Consequently, an equation was established in selecting lower limit potential shear power derived from experimental data, which predicts the load carrying capacity of the angle, T-shaped steel and channel shear connector. The fatigue ability of welded connections in steel cement composite layers between the bottom plate and angle shear connectors has been tested by researchers (Jalali *et al.* 2012, Shariati *et al.* 2012a, Ismail *et al.* 2018, Davoodnabi *et al.* 2019). The shear behavior of the angle shear connection under monotonic loading and reverse cyclic loading was studied by Shariati *et al.* (2014a). The shear connector resistance can be measured by the push-out test. Samples are cast to calculate the powers of various connectors. The compression of the test specimen is pure. Besides, head studs, angle connector and channel connector are the most common used connectors (Fanaie *et al.* 2015, Hu *et al.* 2020a, b). Push-out tests are used to investigate the current research angle shear connectors. This research investigates and presents the behavior and consequences of angle shear connectors under static loading.

Concrete is the most common construction material. The weakness of tensile strength and shear resistance is one of the major drawbacks of concrete (Shariati *et al.* 2011b, Arabnejad Khanouki *et al.* 2016, Faegh and Fanaie 2018, Shariat *et al.* 2018). A number of experiments to solve this vulnerability have been conducted by relying on additional reinforcement components (Sinaei *et al.* 2011, Mohammadhassani *et al.* 2014a, Hosseinpour *et al.* 2018, Xie *et al.* 2019). Over the last decades, the scientific community has focused tremendously on fibers, which can

enhance the mechanical properties of concrete (Luo *et al.* 2019, Toghrolji *et al.* 2020, Mehrabi *et al.* 2021, Rajaei *et al.* 2021). A typical form of fiber is blended into concrete for enhancing the properties of the concrete, including vitreous, synthetic, carbon and steel (Sajedi and Shariati 2019, Naghipour *et al.* 2020a, Shariati 2020, Shariati *et al.* 2020h).

It should also be mentioned that since 1972, significant studies have been carried out in order that traditional shear reinforcement in reinforced and pre-stressed concrete with steel fibers (SFs) could be replaced (Arabnejad Khanouki *et al.* 2010, Ataei *et al.* 2014, Shariati *et al.* 2020c, i). The plastics and drying shrinkage in concrete was first regulated using SFs. More experiments have showed that the addition of SFs with concrete strongly improves bending strength and tensile strength, energy absorption potential, ductility behavior, cracking reduction and shear performance (Shah *et al.* 2016b, Partovi and Fanaie 2020, Shariati *et al.* 2020a, Yazdani *et al.* 2020). This is why steel fiber reinforced concrete (SFRC) has become very common for various applications of the civil engineering industry including tunnel shells, concrete sewer pipes, higher top-level layers and massive industrial building plates (Shariati 2008, Chen *et al.* 2019a, Shariati *et al.* 2019a, Razavian *et al.* 2020). In spite of the numerous benefits, it is still hard to assess the vital potential using traditional methods (Dallam 1968, Dedic and Klaiber 1984, MacArthur 2013, Asadolahi and Fanaie 2020) to develop the SFRC structures. Various computational experiments on SFRC were conducted in the literature to examine shear strength (Dai *et al.* 2015, Safa *et al.* 2019, Naghipour *et al.* 2020b, Shariati *et al.* 2020b). Regarding that, the shear strength of concrete beams with fibers can be predicted taking account of the breakage width and shear crack slips. In order to approximate the shear strength of the SFRC beams with a less ratio, a balance based on the fundamental mechanic's theorem was also suggested (Hamidian *et al.* 2011, Mohammadhassani *et al.* 2014c, Nasrollahi *et al.* 2018, Shariati *et al.* 2018). In the end, various shear experiments have been conducted on prismatic beams to provide valuable knowledge on SFRC (Šabatka *et al.* 2015, Khorami *et al.* 2017a, Shariati *et al.* 2019c, Trung *et al.* 2019b). Over the past four decades, several empirical formulations have been suggested in the literature to estimate SFRC shear power (Fanaie and Tahriri 2017, Toghrolji *et al.* 2017, Milovancevic *et al.* 2019, Suhatriil *et al.* 2019). However, because of the precision and uniformity of the proposed equations, there is a considerable gap between current experimental findings and prediction formulations (Shah *et al.* 2016a, Nosrati *et al.* 2018, Toghrolji *et al.* 2018, Shariati *et al.* 2019f). Laboratory tests are able to provide reliable results, but numerical methods can also lead to accurate findings with lower costs (Shariati *et al.* 2012e, 2017, Shariati 2013, Shahabi *et al.* 2016). For example, one of the numerical approaches for solving differential equations is finite element method (FEM) (Arabnejad Khanouki *et al.* 2011, Daie *et al.* 2011, Sinaei *et al.* 2012, Khorramian *et al.* 2017). In fact, FEM can be employed for simulation in different applications such as structural assessment, heat transfer, fluid flow and mass transfer (Shariati *et al.* 2011c, 2019b, 2020g). The performance of shear connectors has been also evaluated by

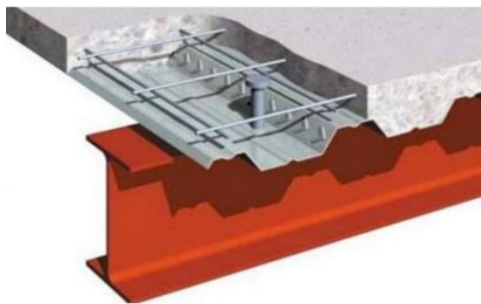


Fig. 1 Steel concrete shear connection

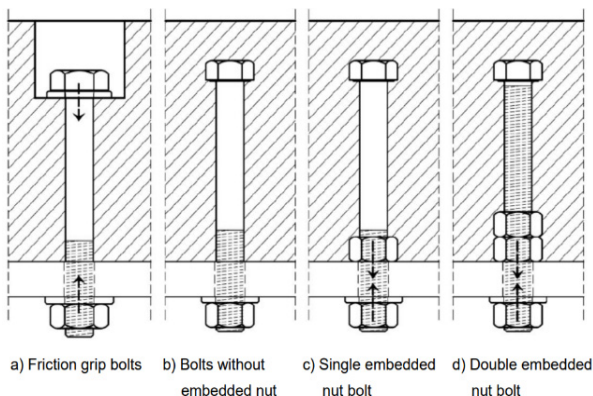


Fig. 2 Demountable bolted shear connector

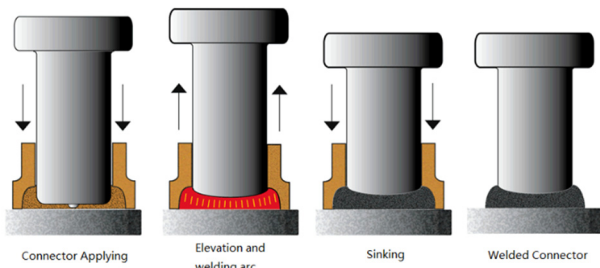


Fig. 3 Shear connector

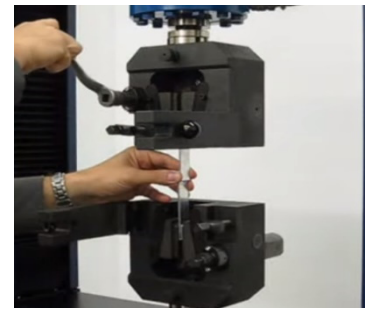


Fig. 5 Test set up

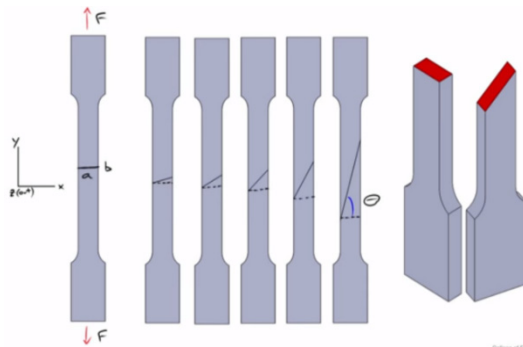


Fig. 4 Normal and shear stresses at various angles in a shear spaceman

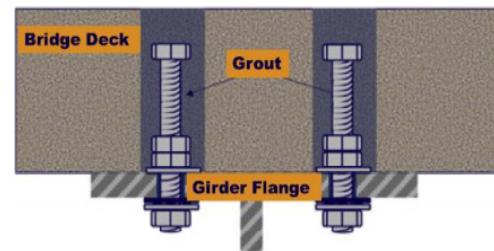


Fig. 6 Shear connection layout

FEM in many investigations (Khorramian *et al.* 2015, Khorami *et al.* 2017b, Wei *et al.* 2018, Afshar *et al.* 2020). In recent years, Artificial Intelligence (AI) has been widely applied in different fields (Mohammadhassani *et al.* 2014b, Safa *et al.* 2016, Trung *et al.* 2019a). In comparison with experimental studies and numerical simulation, AI algorithms are faster and more accurate (Shariati *et al.* 2010, Shah *et al.* 2016c, Heydari and Shariati 2018). AI is able to solve sophisticated problems based on human neurons. In civil engineering applications, numerous papers have employed AI techniques in which reliable results were obtained (Shariati *et al.* 2012c, 2013, Zandi *et al.* 2018,

Katebi *et al.* 2019). In addition, different types of AI methods have been developed and utilized such as artificial neural networks (ANNs) and machine learning (Mohammadhassani *et al.* 2013, Toghroli *et al.* 2016, Mansouri *et al.* 2019, Shariati *et al.* 2019g). Adaptive Network-Based Fuzzy Inference System (ANFIS), Gray Wolf Optimizer (GWO) and Support Vector Machine (SVM) are also considered in the field of AI algorithms (Safa *et al.* 2020, Shariati *et al.* 2020d). Moreover, in order to solve multiobjective optimization problems, hybrid intelligent algorithms such as GWO-ELM, ANN-PSO and SVM-PSO are used (Shariati *et al.* 2020j, 2019d, 2020e, 2020f). The shear capacity of channel shear connectors was studied by Toghroli *et al.* (2014) using an ANFIS model. They compared results with linear regression (LR). It was

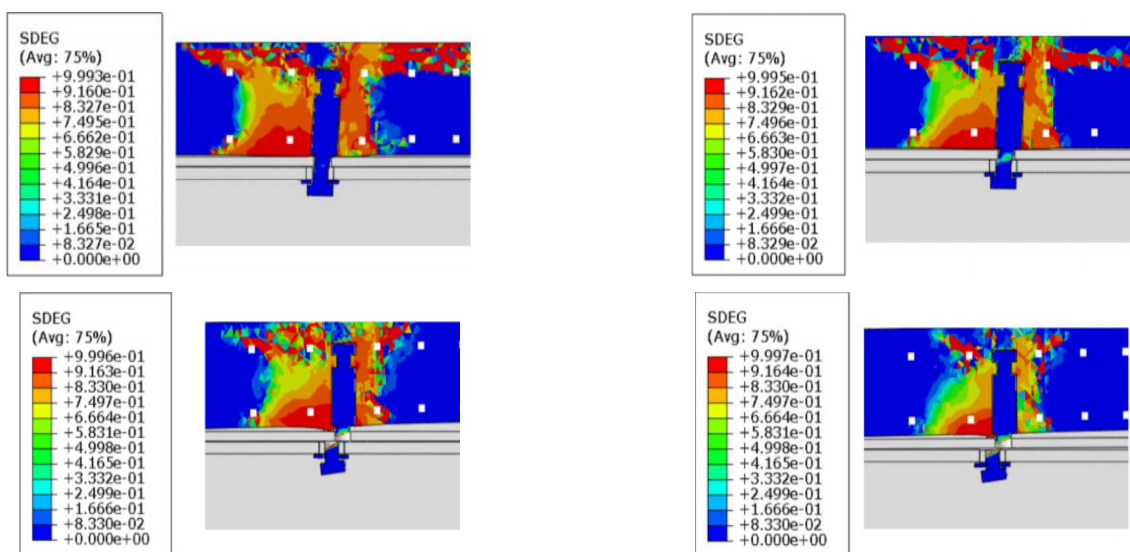


Fig. 7 Stiffness degradation for different concrete strength classes

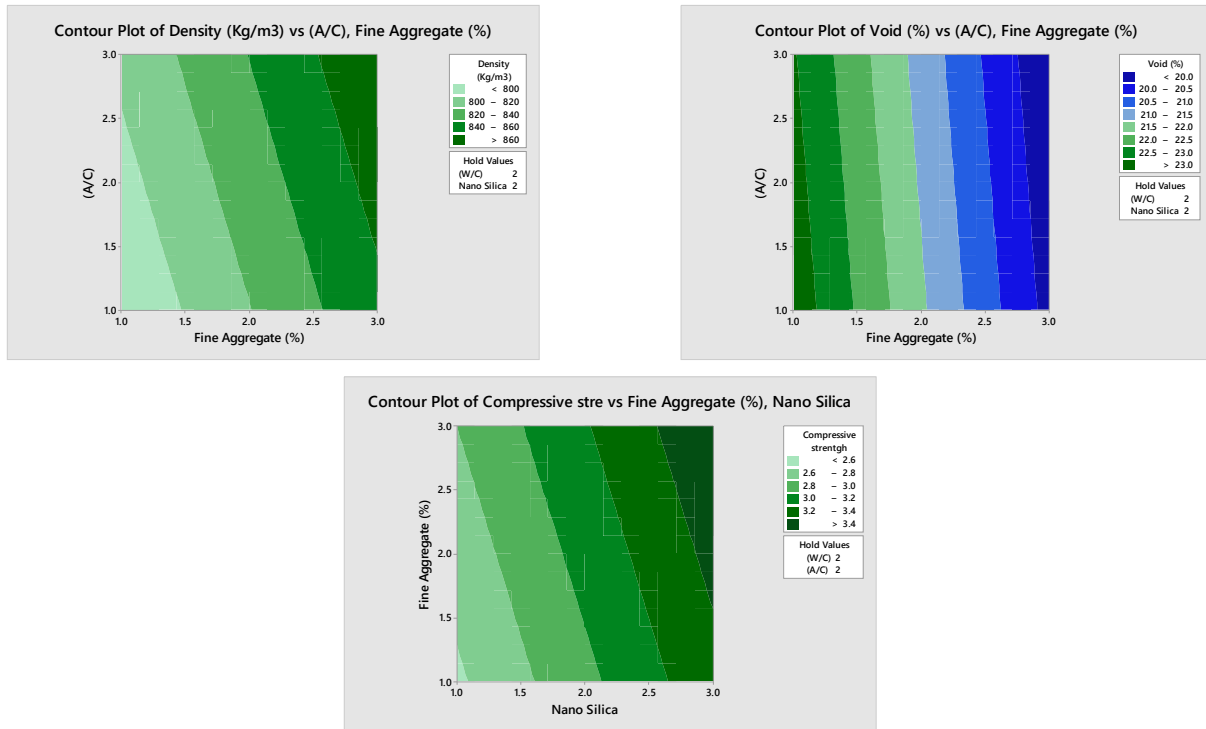


Fig. 8 Contour plot of responses via their two most important factors

found that ANFIS produce accurate results compared to LR. In another study, SVM and Firefly Algorithm were applied to determine the influential parameters on the shear strength of angle shear connectors (Sadeghipour Chahnasir *et al.* 2018). The performance of concrete slabs in composite beam with two types of angle shear connectors was studied using FEM and soft computing method (Sedghi *et al.* 2018).

SVM, ANFIS, and ANN have been used to predict the compressive strength of concrete structures. Besides, the performance of building structures under different loading conditions can be evaluated by AI algorithms (Milivojevic *et al.* 2012, Alam *et al.* 2020a, b, Abedini and Zhang 2021). Neural network (NN) models generally require several parameters, such as transmission functions and particularly the numbers of neurons and hidden layers to determine the structures of a NN (Pazhoohan *et al.* 2019, Cao *et al.* 2020, Iqtidar *et al.* 2021, Khan *et al.* 2021). The alternative modeling method for prediction of behavior of structural problems could be considered as genetic programming (GP) (Panda *et al.* 2014, Qi and Fourie 2019, Shariati *et al.* 2019e, Qi *et al.* 2020).

### 1.1 Problem statement

Understanding the shear strength of concrete is important to predict the strength of shear connector in construction projects. Predicting this strength in experimental tests needs more time and high expenses, besides that gathering the raw data is highly difficult and not feasible. However, using soft computing could predict this faster and more accurate with the least error percentages. Accordingly, this study by the use of GWO has attempted to predict the shear strength of shear connector.

### 1.2 The numerical analysis of shear connector

In this study, two types of failure modes, i.e., compressive crushing failure and tensile cracking failure were used as a CDP (Concrete Weakened Plasticity) model for simulating the elastic-plastic behavior of concrete in ABAQUS 6.14. The dilatation angle, flow eccentricity and viscosity coefficient of the finite element models in this paper have been defined at 31, 0.1 and 0.0001, respectively. Furthermore, the uniaxial force/biaxial power ratio ( $f_{b0}/f_{c0}$ ) was 1.16. Since it was believed that the fracture of the concrete was started when the tensile strain was more than ten times higher than the normal concrete fracture  $\mu_c, \tau$  (Dai *et al.* 2015), CDP cannot explain the initiation and formation of fractures to replicate a concrete fracture. The concrete lost its resistance to cracking as it reached the ultimate traction pressure.

### 1.3 Constitutive relationship of concrete

Following the Chinese code for concrete design (Weijian and Xiaohuangcan 2017),  $E_c$  (elasticity modulus) and Poisson's ratio  $\nu_c$  of concrete is

$$E_c = \frac{10^5}{2.2 + (34.7 / f_{cm})} \quad \nu_c = 0.2 \quad (1)$$

$f_{cm}$  = mean value of compressive strength

Code (Weijian and Xiaohuangcan 2017) has developed specific stress training relationships for the uniaxial strain and compression of the concrete. A specific composing relationship is defined as under uniaxial compression.

$$\sigma = (1 - d_c)E_c\varepsilon$$

$$d_c = \begin{cases} 1 - \frac{p_c n}{n - 1 + x^n} x & x \leq 1 \\ 1 - \frac{p_c}{a_c(x - 1)^2 + x} & x > 1 \end{cases},$$

$$x = \frac{\varepsilon}{\varepsilon_{c,r}}$$

$$p_c = \frac{f_{c,r}}{E_c \varepsilon_{c,r}}$$

$$n = \frac{E_c \varepsilon_{c,r}}{E_c \varepsilon_{c,r} - f_{c,r}} \quad (2)$$

$d_c$  = the damage evolution parameter of concrete under uniaxial compression

$\varepsilon$  = the compressive strain of concrete

$a_c$  = for the descent segment parameter in a constitutive relationship of concrete in uniaxial compression,

$f_{c,r}$  = uniaxial compressive strength

$\varepsilon_{c,r}$  = the peak compressive strain corresponding to  $f_{c,r}$

The corresponding values of both  $\alpha_c$  and  $\varepsilon_{c,r}$  were gained by linear interpolation for different compressive strengths shown in Table 1 based on the suggested details in Table 2. The constitutive connection between the concrete and uniaxial stress is expressed

$$\sigma = (1 - d_t)E_c\varepsilon$$

$$d_t = \begin{cases} 1 - \rho_t(1.2 - 0.2x^5), & x \leq 1, \\ 1 - \frac{\rho_t}{a_t(x - 1)^{1.7} + x}, & x > 1, \end{cases} \quad (3)$$

$$x = \frac{\varepsilon}{\varepsilon_{t,r}} \quad \rho_t = \frac{f_{t,r}}{E_t \varepsilon_{t,r}}$$

$\varepsilon_{t,r}$  = the peak tensile strain corresponding to  $f_{t,r}$

$d_t$  = damage evolution parameter of concrete under uniaxial tension

$f_{t,r}$  = the uniaxial tension strength of concrete

$a_t$  = the parameter for descent segment in a constitutive relationship of concrete under uniaxial tension,

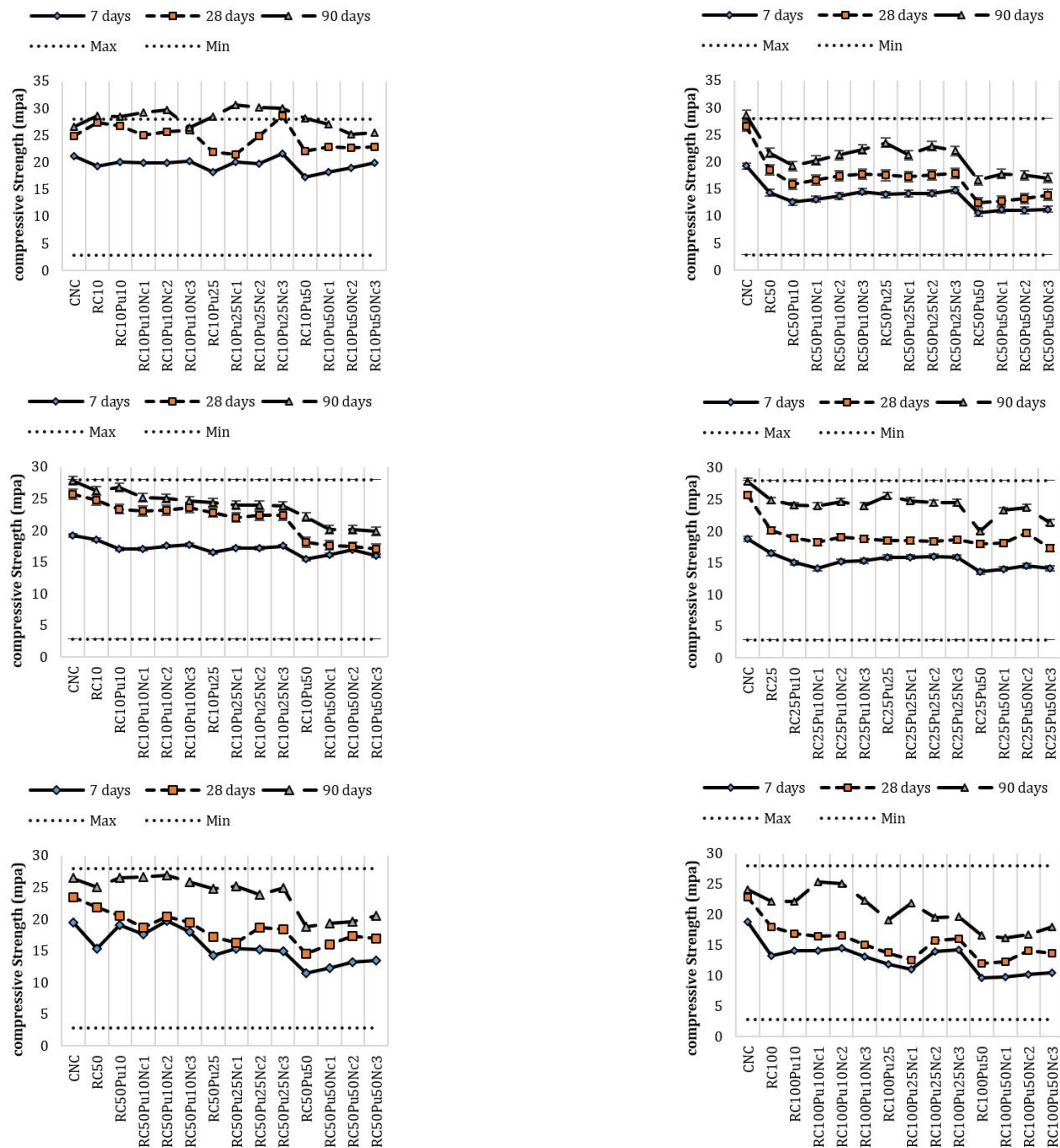


Fig. 9 The effect of adding Superplasticizer in 7, 28 and 90 days curing period on the compressive strength in concrete

Table 1 Chemical composition of the used aggregates and cement

Composition (percent)	Portland cement	Zeolite	Perlite	Nano silica
SiO <sub>2</sub>	20.5	72.86	67.5	98.5
Al <sub>2</sub> O <sub>3</sub>	5.3	15.8	8.45	-
CaO	64.5	1.56	2.56	-
Fe <sub>2</sub> O <sub>3</sub>	3.6	1.5	3.3	-
MgO	2.8	0.48	4.3	0.5
K <sub>2</sub> O	-	4.1	3.2	-
SO <sub>3</sub>	1.5	-	-	0.5
Na <sub>2</sub> O	-	3.7	2.0	-
LOI	1.8	-	1.56	0.5

Table 2 Factors and their variation levels

Level	W/C	A/C	Nano silica	Fine aggregate (%)
1	0.26	3	0	0
2	0.35	4	0.03	10
3	0.45	5	0.06	20

The tension strength for different standard concrete was taken for 10% of its compression power because of the absence of empirical results, which was also followed by (Shamass *et al.* 2015) in the research.

#### 1.4 Constitutive relationship of SFRC

Taking into account the influence of F (Ning *et al.* 2015) fiber, the damaging SFRC relationship could be shown in uniaxial compression as follows

$$\sigma = E\varepsilon \exp \left[ - \left( \frac{\varepsilon}{0.00052F + 0.0025} \right)^{(-1.091F + 1.983)} \right], \quad (4)$$

$$F = \beta V \frac{L_f}{d_f}$$

$E$  = modulus of elasticity of SFRC without damage

$\varepsilon$  = compressive strain of SFRC

$\beta$  = bond coefficient of fiber related to the geometric properties of fiber

$V_f$ ,  $L_f$ , and  $d_f$  = volume fraction, length, and diameter of the fiber, respectively.

Table 3 Concrete mix design based on Taguchi method (4 factors in 3 levels)

Num.	(W/C)	(A/C)	Nano silica	Fine aggregate (%)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

In fact, this is a very simplified method of deriving the SFRC traction behavior. Any kind of reverse bending analysis should be used if possible to extract the tensile characteristics of SFRC materials.

#### 1.5 Constitutive relationship of epoxy

In the sample, the bonding strength of the interface between concrete and epoxy was 22 MPa, which was significantly greater than the tensile strength of concrete (Chen *et al.* 2019b) for epoxied joint specimens. In contrast, the strength of epoxied compressive and tensile was stronger than that of concrete. Consequently, all epoxied specimens failed in shear or in concrete tensile. Easily, the epoxy was set as an elastic medium in the finite-element model with a 4,826 GPa elastic module and a Poisson ratio of 0.2, respectively (Shamass *et al.* 2015).

#### 1.6 Constitutive relationship of steel rebar

In order to reflect the constitutive relationship of strengthening, an elastic plastic bilinear model was set up. This relationship of stress can be expressed as

$$\begin{aligned} \sigma_s &= E_s \varepsilon_s, & \varepsilon_s &\leq \varepsilon_y \\ \sigma_s &= f_y, & \varepsilon_s &> \varepsilon_y \end{aligned} \quad (5)$$

$E_s$  = elastic modulus of steel rebar,

$f_y$  = yield strength of reinforcement,

$\varepsilon_y$  = strain at yield strength of steel rebar.

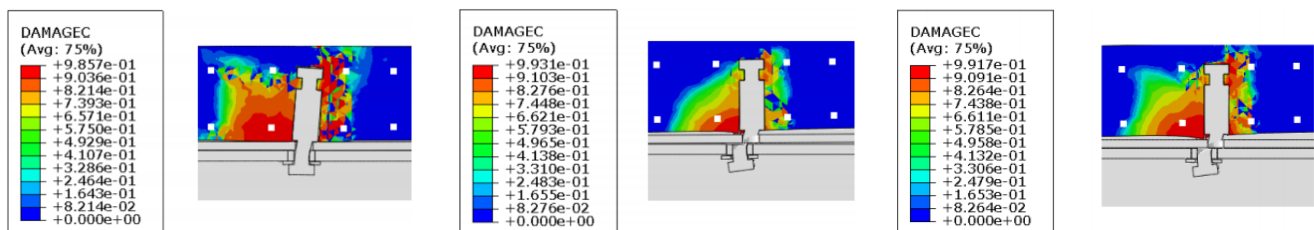


Fig. 10 Comparison of concrete compressive damage for different concrete strength classes

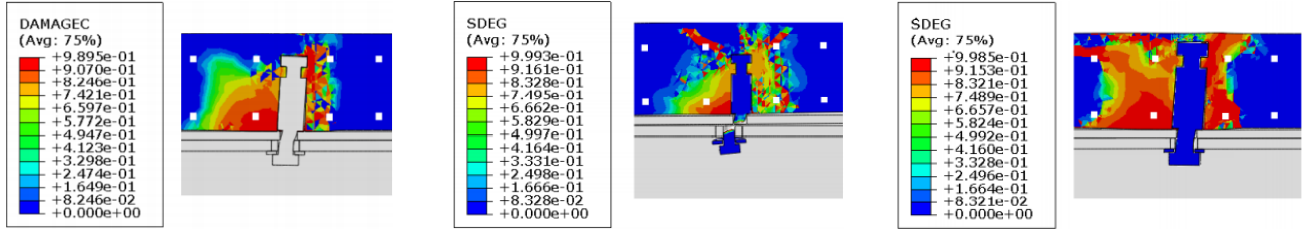


Fig. 11 Comparison stiffness degradation for various bolt diameters

Table 4 Regression results of response

Result	Standard deviation	$R^2$	$R^2$ (adjusted)	Regression equation
Nitrate removal	3.41	98.8	97.5	$= -10.0 + 0.500 (W/C) + 3.0 (A/C) + 16.5 \text{ Nano silica} + 5.0 \text{ Fine aggregate } (\%)$
Permeability (cm/s)	2.57	99.4	98.9	$= 1.70 - 0.0267 (W/C) + 0.00500 (A/C) - 0.00500 \text{ Nano silica} - 0.205 \text{ Fine aggregate } (\%)$
Compressive strength (MPa)	4.35	98.5	97	$= 1.90 + 0.0333 (W/C) + 0.0500 (A/C) + 0.383 \text{ Nano silica} + 0.117 \text{ Fine aggregate } (\%)$
Void (%)	3.61	98.6	97.2	$= 25.1 + 0.027 (W/C) - 0.133 (A/C) + 0.017 \text{ Nano silica} - 1.73 \text{ Fine aggregate } (\%)$
Density (Kg/m <sup>3</sup> )	5.25	94.5	92	$= 731 - 0.67 (W/C) + 10.7 (A/C) + 3.33 \text{ Nano silica} + 36.0 \text{ Fine aggregate } (\%)$

## 2. Methodology

### 2.1 Materials

180 empirical datasets have been collected on FRC from the reliable literature comprising the input values of concrete mixtures, fiber information and one output variable as the final shear strength of concrete.

### 2.2 Grey Wolf Optimizer (GWO)

The motivation behind GWO was the hierarchical society of gray wolves with some wolves and hunting practices (Fig. 11) including alpha ( $\alpha$ ), beta ( $\beta$ ) (help wolves) and omega ( $\omega$ ) (scapegoat).

The Delta ( $\delta$ ) group is a group which does not participate in three other groups. Grey Wolf Optimizer consists of the surrounding, attack and prey chase (Fig. 6) and the quest for another prey (8), (9).

$$\vec{D} = |\vec{C} \cdot \vec{X}_p(t) - \vec{X}(t)| \quad (6)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A} \cdot \vec{D} \quad (7)$$

$t$  = the current moment

$\vec{X}_p$  = the vector location of a prey

$\vec{X}$  = GW position in a circular configuration

$\vec{A}$  and  $\vec{D}$  = the coefficient vectors

Defined:

$$\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a} \quad (8)$$

$$\vec{C} = 2 \cdot \vec{r}_2 \quad (9)$$

$\vec{r}_1$  and  $\vec{r}_2$  = random vectors uniformly distributed between 0 and 1

$a$  = linearly reduced from 2 to 0

With regard to the undefined prey place (optimal position),  $\alpha$ ,  $\beta$  and  $\delta$  wolves will be best informed of the situation. In addition, the mean location of the wolf is used to find the position of the prey.

Then:

$$\begin{aligned} \vec{D}_\alpha &= |\vec{C}_1 \cdot \vec{X}_\alpha - \vec{X}|, & \vec{D}_\beta &= |\vec{C}_2 \cdot \vec{X}_\beta - \vec{X}|, \\ \vec{D}_\delta &= |\vec{C}_3 \cdot \vec{X}_\delta - \vec{X}| \end{aligned} \quad (10)$$

$$\begin{aligned} \vec{X}_1 &= \vec{X}_\alpha - \vec{A}_1 \cdot \vec{D}_\alpha, & \vec{X}_2 &= \vec{X}_\beta - \vec{A}_2 \cdot \vec{D}_\beta, \\ \vec{X}_3 &= \vec{X}_\delta - \vec{A}_3 \cdot \vec{D}_\delta \end{aligned} \quad (11)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad (12)$$

The process of its hunting (exploitation) is carried out by vector  $A$  dairy to determine the location of the prey. That is because the position of wolves is decreased from 2 to 0 in Eq. (8) so that it reaches prey (8). The hunt (exploitation) and the prevention of local minima in this model, on the other hand, contribute factors  $C$  and  $A$ . Although parameter  $C$  might change the prey and the toughness of their hunting,  $A$  is greater than 1 ( $|A| > 1$ ) which obliges the gray wolves to differentiate themselves from the current prey and to find another. The same applies (13) reveals the place of the optimal global point or prey (Han *et al.* 2019) where there is not much appropriate procedural iteration of the gray wolf population.



Fig. 12 (a) Finding and tracking; (b) pursuit; (c) harass; (d) encircling; (e) final stationary configuration at the end of hunting (Shariati et al. 2020d)

Table 5 Comparison results of GWO in both phases

AI model	Training phase		Testing phase	
	$R^2$	RMSE	$R^2$	RMSE
GWO	0.9881	0.8502	0.9710	0.9057

### 3. Result and discussion

#### 3.1 Model performance indicators

According to the data, 70% of the data is used in train stages and 30% in the test stage. The root mean square (RMSE) and the determination coefficient ( $R^2$ ) indices were used in MATLAB for comparing the performance of the individual trains with the test stage (ELM, GWO, GWO-ELM).

$$R^2 = \frac{[\sum_{i=1}^N (O_i - \bar{O}) \cdot (P_i - \bar{P})]^2}{\sum_{i=1}^N (O_i - \bar{O}) \cdot \sum_{i=1}^N (P_i - \bar{P})} \quad (13)$$

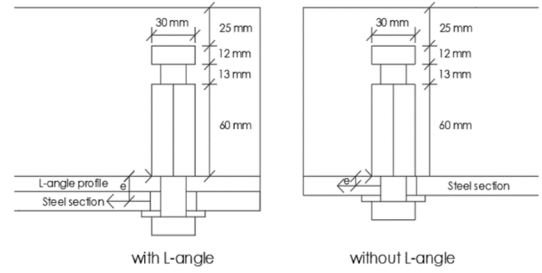


Fig. 13 Cross section of FE model with and without L- angle profile

$$RMSE = \sqrt{\sum_{i=1}^N \frac{1}{N} (O_i - P_i)^2} \quad (14)$$

$O_i$  = observed values in sample  $i$

$\bar{P}$  = predicted values

$P_i$  = predicted values in sample  $i$

$N$  = number of training or testing samples

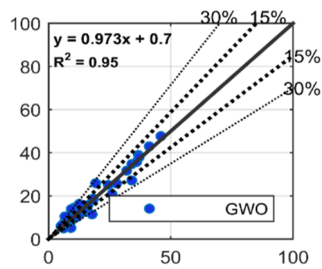
$\bar{P}$  = predicted values

$\bar{O}$  = mean of observed variables

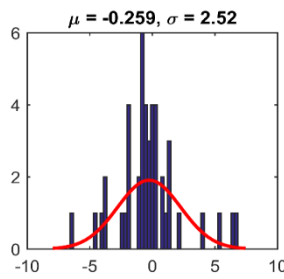
#### 3.2 Data analysis

It was executed after an analysis of the criteria involved in GWO and was tested in previous preparation and test phases for the role of previous success metrics (Table 5). The RMSE and  $R^2$  ( $RSQR$ ) values were compared in the preparation and test phases compared with those of GWO. The best RMSE value is obviously close to 0. Accordingly, by comparing the RMSE of GWO (0.9057) in testing and (0.8502) in training phase, it was proved that the RMSE of GWO in training phase showed better performance than test phase in predicting the Strength of Shear Connector. On the other hand, the more  $R^2$  ( $RSQR$ ) value is near to 1, the more it is acceptable. In this case, the  $R^2$  values of GWO (0.9710)

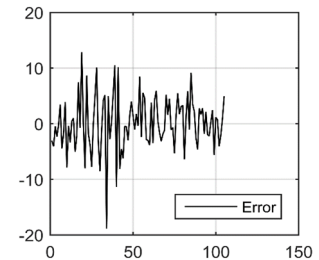
#### Train



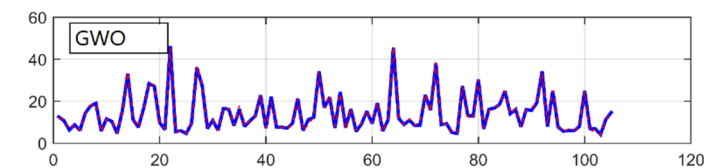
(a) AI results in training phase



(b) Error distribution



(c) Observed error values



(d) Comparison of predicted strength of shear connector in GWO train data

Fig. 14 The diagram of GWO in train phase

## Test

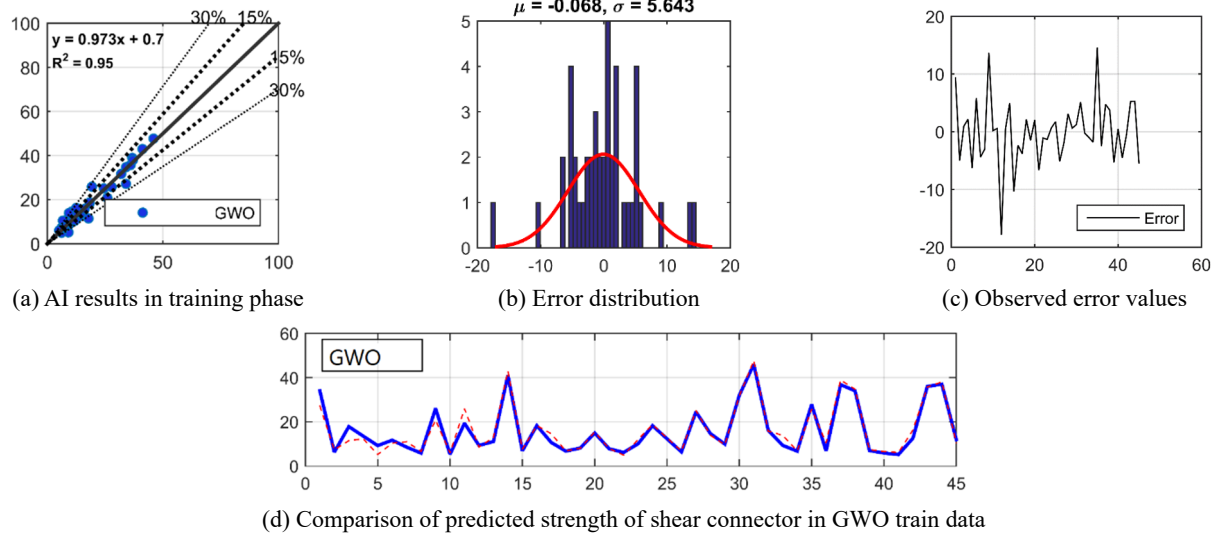


Fig. 15 The diagram of GWO in test phase

in test phase and (0.9881) in train phase were compared, then the best performance metrics of this model is in train phase. On the whole GWO has shown its best performance in predicting the Strength of Shear Connector. The horizontal axis of Figs. 14(a), 15(a) displays the observable shear connector strength during preparation and research, while the vertical axis suggests expected algorithm performance. The horizontal axis in Figs. 14(d) and 15(d) shows the amount of training and evaluation samples and the vertical line shows the shear connector strength in both processes. The blue line in Figs. 14(d), 15(d) shows a 100 percent overlap between the observed values (ideal form) and the predicted variables, while the radial line shows the less accurate of the model with 15 - 30 percent deviation from the blue line. Fig. 14(b) also shows a variance value ( $\sigma$ ) of 2.52, while the mean of value ( $\mu$ ) of 0.259. In figures 15b, the variance of value ( $\sigma$ ) is 5.643, while the mean of value ( $\mu$ ) is -0.068. On the whole, the findings demonstrate GWO's over-performance in estimating the shear connector resistance overall.

#### 4. Conclusions

In this study, GWO was built and used to predict the Strength of Shear Connector. 180 empirical datasets were collected from the literature comprising the input values as concrete mixture and one output value as the shear strength was developed and analyzed. The statistical indicators of  $R^2$ , and  $RMSE$  were used to valid the training and testing datasets to measure the predictive abilities of the proposed algorithm. Comparing the  $RMSE$  values in both phases has shown that GWO could perform better in training phase. As a result, GWO is a promising tool and method to predict the Strength of Shear Connector. Results have shown that web width and effective depth were the most significant parameters effectively affect the shear capacity and the most important factors to model the shear capacities.

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