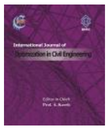
INTERNATIONAL JOURNAL OF OPTIMIZATION IN CIVIL ENGINEERING
Int. J. Optim. Civil Eng., 2020; 10(3):451-479



A PARTICLE SWARM OPTIMIZATION ALGORITHM TO SUGGEST FORMULAS FOR THE BEHAVIOUR OF THE RECYCLED MATERIAL REINFORCED CONCRETE BEAMS

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ABSTRACT

Reducing waste material plays an essential role for engineers in the current world. Nowadays, recycled materials are going to be used in order to manufacture concrete beams. Previous studies concluded that the currently proposed formulas to predict the flexural and shear behavior of the reinforced concrete beams were not appropriate for those manufactured by recycled materials. This study aims to employ the Particle Swarm Optimization Algorithm to suggest the flexural and shear performance of recycled material reinforced concrete beams. For this purpose, the previous experimental outcomes are utilized, and new equations are established to anticipate both flexural and shear behavior of the recycled material concrete beams. Consequently, all findings are compared with those achieved experimentally. The attained significances of this study show that the proposed formulas have high accuracy for the experimental data.

Keywords: flexural resistance; shear strength; par; reinforced concrete beams; waste materials.

Received: 5 February 2020; Accepted: 6 June 2020

Notion					
$M_{cr,ACI}$	cracking moment according to ACI	f_r	modulus of rupture of concrete	y_t	distance from the centroid axis of the cross-section, neglecting the reinforcement, to the tensioned face
I_g	moment of inertia of the cross-section relative to the	λ	modification factor	f_c'	compressive strength of the concrete beam

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	centroid axis, neglecting the reinforcement				
$M_{ult.ACI}$	ultimate moment in doubly-reinforced concrete beams according to ACI	b	span width	$d-d'$	distance between the centroids of the tension and compression reinforcement
A_s	area of the tension reinforcement;	A'_s	area of the compression reinforcement	ρ	reinforcement ratio
d	effective depth	f_y	yield strength of steel	$M_{cr.CSA}$	cracking moment according to CSA
M_{fc}	factored resisting moment of the concrete and bottom steel	α_1	ratio between the average stress in the rectangular compression block and the specified concrete strength	β_1	ratio between the depth of the rectangular compression block and the depth of the neutral axis
$M_{cr.Euro}$	cracking moment according to Eurocode 2	f_{ctm}	mean tensile strength of concrete	I_u	second moment of the cross-section for uncracked condition
h	height of the cross-section	x_u	neutral axis depth for uncracked condition	f_{ck}	characteristic compressive concrete strength
V_r	factored shear resistance	V_c	shear resistance attributed to concrete factored by φ_c	V_s	shear resistance provided by shear reinforcement factored by φ_s
V_p	shear resistance provided by a component in the direction of the applied shear of the effect a force factored by φ_p	φ_c	resistance factor of concrete	d_v	effective shear depth
θ	the angle of diagonal compressive stresses to the longitudinal axis of the member	S	transverse reinforcement spacing	$V_{R.pred}$	predicted value of shear strength
$V_{R.c}$	shear strength attributed to concrete	$V_{R.s}$	shear strength provided by the stirrup	$V_{R.max}$	maximum allowed shear strength
z	inner lever arm	ε_x	longitudinal strain at mid-depth of beam	E_s	reinforcement steel modulus of elasticity
d_g	maximum aggregate size	f_{st}	transverse reinforcement yield stress	V_u	factored cross-section shear force

1. INTRODUCTION

Using wastes can help to protect the environment. Recycled materials could be utilized to manufacture concrete elements. These resources can be replaced with cement, aggregate or be added to the concrete mix as additions [1]. Many types of research have been done on using recycled materials in order to manufacture concrete beams. Azad [2] assessed the flexural performance of reinforced concrete beams made with recycled waste materials. In this study, PET wastes were employed as recycled material. For this aim, compressive strength, maximum load capacity, load-deformation relationship, stiffness and failure modes of the specimens were measured. Seara-Paz et al. [3] evaluated the impact of recycled coarse aggregate on the bending performance of reinforced concrete beams. Eight specimens were produced by using four recycled aggregate replacement ratios of 0%, 20%, 50% and 100%. Specimens were tested under a four-point setup after 28 days. In this research, bending moments, load-deflection curve, strains and curvatures were assessed. According to the obtained outcomes, the cracking comportment demonstrated the differences between recycled aggregate and original concrete.

Tarek et al. [4] utilized brick as an aggregate to manufacture concrete beams. For this aim, twenty-four laboratory samples were made with 250 mm height, 200 mm width and 2100 mm length. To measure the bending performance of concrete beams, the outcomes were compared with the requirements of ACI 318-14. In comparison with the virgin brick aggregate, the use of recycled brick aggregate did not reduce the cracking moment nor the ultimate flexural capacity of the specimens. In another study, Choi and Yun [5] studied long-term deflection, and flexural behavior of the recycled aggregate reinforced concrete beams. In this study, specimens were tested under the long-term loading for 360 days. Specimens were produced with 100% natural aggregate, 100% recycled aggregate, and 50% natural aggregate plus 50% recycled aggregate. Also, the experimental consequences were compared with those obtained numerically based on ACI 318 formulas. Consequently, a formula was modified to forecast the long-term flexural deformation. Besides, the crack patterns were measured for all the aggregate types. It is found that more cracks occurred in the beams made with the recycled aggregate.

Gao and Zhang [6] examined the flexural behavior of the steel fibre reinforced recycled coarse aggregate concrete. For this purpose, steel fibres were utilized at 0%, 0.5%, 1%, 1.5% and 2% of the volumetric contents. Moreover, recycled coarse aggregates were replaced with natural aggregates at 0%, 30%, 50% and 100% per volume. Results illustrated that the flexural resistance, toughness and deformation radically raised by increasing the value of recycled aggregates. In another investigation, Arora and Singh [7] evaluated the flexural performance of concrete beams manufactured with 100% recycled coarse aggregate under the flexural fatigue failure. In this study, $100\ mm \times 100\ mm \times 500\ mm$ specimens were manufactured and tested. Four-point flexural loading was employed to assess the behavior of beams. The achieved consequences were compared with those produced using the natural aggregates. According to the results, it was illustrated that using 100% recycled aggregate in concrete resulted in poor fatigue performance. Tošic et al. [8] compared the flexural behavior of recycled aggregates reinforced concrete beams with Eurocode code's equations, based on 217 experimental specimens. They showed that Eurocode could estimate the flexural and shear strength of recycled aggregates concrete beams without transverse reinforcement, and the requirements of this standard should be improved when stirrups were used over the specimens. In another paper, Zaetang et al. [9] used recycled break aggregates at six contents of 0%, 20%, 40%, 60%, 80%, and 100% in terms of weight. The compressive strength, density, total voids, water permeability, thermal conductivity and surface abrasion resistance of the concrete containing these aggregates were examined. Even though the recycled aggregates were weaker than the natural aggregates, improvements in strength and abrasion resistance were achieved. This was as a result of better bonding between the recycled aggregates and the cement paste due to the increased surface porosity and roughness of recycled aggregates. Recently, Chaboki et al. [10] evaluated the flexural performance of steel fibers recycled aggregates reinforced concrete beams. In this study, 27 RC beams were manufactured and tested. Steel fibres were added at three contents of 0%, 1% and 2%. Furthermore, recycled coarse aggregates were replaced at three mass replacement: 0%, 50% and 100%. The obtained outcomes indicated that steel fibres and stirrup spacing have a significant effect on the flexural behavior of recycled aggregates reinforced concrete beams.

In 2018, Pradhan et al. [11] studied the shear performance of recycled aggregate concrete beams. The shear failure occurred brittle and suddenly. Therefore, this failure was unsafe if it was not appropriately designed. For this purpose, fourteen specimens were manufactured and tested. Additionally, the influence of transverse reinforcement was considered to evaluate the shear behavior of beams. In this study, six specimens were selected with no stirrup to assess the contribution of recycled concrete in shear resistance mechanisms and in eight specimens, the adequate stirrup was provided. The inferior mechanical characteristics of the recycled aggregate concrete beams were enhanced acceptably by implementing the Particle Packing Method of mix design approach along with the established Two-Stage Mixing Approach. Based on the achieved results, the maximum shear strength was dropped approximately 14%, when recycled aggregates were used. In 2018, Etman et al. [12] tested a total of eleven RC with simply supported manufactured by recycled aggregates along with one conventional concrete beam. The specimens were tested under a four-point bending setup. In addition, recycled aggregates were used at three-volume replacement contents of 15%, 30% and 45%. Correspondingly, the shear span-to-depth ratio was 1, 2 and 3. The obtained experimental consequences illustrated that the shear strength was decreased by 8%, 14% and 19% for replacement content of recycled aggregates 15%, 30% and 45%, correspondingly. Rahal and Alrefaei [13] measured the shear strength of the recycled aggregates concrete beams. For this purpose, eighteen laboratory samples were manufactured and examined. Recycled aggregates were used at three-volume contents of 0%, 20% and 100%. Furthermore, the ratio of the longitudinal reinforcement in all the beams was 1.38%. Results of this study demonstrated that the shear strength did not importantly decrease by utilizing recycled aggregates; however, these aggregates affected the cracks' pattern substantially.

In another investigation, Ignjatovic et al. [14] studied the shear behavior of RAC beams by paying attention to the transverse reinforcement spacing. Nine simply supported beams were manufactured and tested under the four-point bending test. Loading was performed until complete failure. Recycled aggregates were introduced into the concrete mixes at 0%, 50% and 100% in terms of volume. Furthermore, three stirrup ratios were considered (0%, 0.14% and 0.19%). According to the outcomes, it was found that the shear behavior and the shear strength of the specimens manufactured with 50% and 100% of Recycled aggregates were very similar to those that manufactured with natural aggregates. Lately, Chaboki et al. [15] examined the shear behavior of concrete beams with recycled aggregate and steel fibres. This paper mostly studied the shear properties of reinforced concrete beams manufactured using recycled coarse aggregates and steel fibres. For this aim, twenty-seven specimens with different stirrup spacing were produced. Recycled aggregates were employed in the concrete mixes at 0%, 50% and 100% replacement values. Besides, steel fibres were used in the beams at 0%, 1% and 2%. In this test, the maximum deflection, shear capacity, mid-span deflection of the beams and tension strain were measured. The outcomes of this experiment and the requirements shown in the standards (e.g. CEB-fib model code, ACI and CSA) were compared. The results showed that steel fibres improved the specimens’ maximum strain, and their use enhanced the shear behavior of recycled aggregates reinforced concrete beams relative to control specimens. Mahmoudi et al. [16] used this tool to determine a relationship for the Chaboche kinematic hardening. It is worth mentioning that many other studies were, done to find an accurate equation by using genetic algorithms [17-19]. Additionally, several researchers presented some ways of parameter determination for the different tests [20].

Previous studies, such as, by Chaboki et al. [10, 15], illustrated that the proposed formulas presented by standards could not predict the shear and flexural performance of the reinforced concrete beams, containing recycled aggregates. This means that the related requirements should be improved. In order to determine the performance of recycled aggregate reinforced concrete beam, Particle Swarm Optimization Algorithm is employed to propose an appropriate equation in the present article. For this purpose, the previous experimental findings are utilized. To find the general equation, several parameters, such as, compressive strength of the concrete, the ratio of the longitudinal reinforcement, the cross-section area of the specimens, length of the beam, yield resistance of the rebars, transverse reinforcement spacing and the ratio of the span width to height of the specimens are used as the input variables. The results show that the recycled coarse is an important parameter in predicting the flexural and shear performance of recycled aggregate reinforced concrete beams.

2. FLEXURAL PERFORMANCE OF REINFORCED CONCRETE BEAMS

In this section, the proposed formulas by well-known standards, ACI 318, were defined [21]. To predict the cracking and ultimate moment, the presented equation is introduced. According to this code, the cracking moment ($M_{cr.ACI}$) can be determined as:

$$M_{cr.ACI} = \frac{0.62\lambda\sqrt{f_c'}I_g}{y_t} \tag{1}$$

where, f_c', I_g and y_t are the concrete compressive strength (Mpa), the moment of inertia of the cross-section relative to the centroid axis, neglecting reinforcement (m^4), and the distance from the centroid axis of the cross-section, neglecting reinforcement, to the tensioned face (m), respectively. Furthermore, the ultimate moment in doubly-reinforced concrete beams can be calculated:

$$M_{ult.ACI} = A_s' f_y (d - d') + (A_s - A_s') f_y (d - \frac{(A_s - A_s') f_y}{20.85 f_c' b}) \tag{2}$$

where, b = span width (mm), $d - d'$ = distance between the centroids of the tension and compression reinforcements (mm), A_s = area of the tension reinforcement (mm^2), A_s'= area of the compression reinforcement (mm^2), ρ = reinforcement ratio, d = effective depth (mm), f_y = yield strength of steel (MPa). According to CSA-A23.3-04_2 [22], equations are based on the normal assumptions of the flexural theory of the reinforced concrete beams. Therefore, the cracking moment can be calculated according to this code as follows:

$$M_{cr.CSA} = \frac{0.6\lambda\sqrt{f_c'}I_g}{y_t} \tag{3}$$

Furthermore, the ultimate moment strength can be obtained in doubly-reinforced concrete beams as:

$$M_{ult.CSA} = M_f - C\left(d - \frac{a_b}{2}\right) \tag{4}$$

M_f is the factored resisting moment of the concrete and bottom steel. Conversely, Eurocode 2 [23] provides a different equation to calculate the cracking moment of reinforced concrete beams:

$$M_{cr.Euro} = \frac{f_{ctm}I_u}{(h - X_u)} \tag{5}$$

where, f_{ctm}, I_u, h and X_u are the mean tensile strength of concrete, the second moment of area for the uncracked condition, the height of the cross-section and the neutral axis depth for the uncracked condition, respectively. To calculate the ultimate flexural moment, Eurocode 2 suggests the following equation:

$$M_{ult.Euro} = K_{lim}f_{ck}bd^2 \tag{6}$$

Here, K_{lim} is a variable parameter given in Eurocode 2 and f_{ck} the characteristic compressive concrete strength (MPa).

3. SHEAR PERFORMANCE OF REINFORCED CONCRETE BEAMS

CSA-A23 [22] presents an equation to predict the reinforced concrete beams' shear strength (V_r), as follows:

$$V_r = X1\varphi_c\lambda\beta\sqrt{f_c'}b_w d_v + X2\frac{\varphi_c A_v f_y d_v \cot\theta}{S} + V_p \tag{7}$$

where, V_r, V_s and V_p are total ultimate shear strength, ultimate shear strength of concrete, the ultimate shear strength of shear reinforcement and component in the applied shear's direction of the effective prestressing force factored by φ_p. Additionally, A_v, θ, f_y and S are the area of shear reinforcement; the angle of the diagonal compressive stresses to the longitudinal axis of the member, the specified yield strength of non-pre-stressed reinforcement or anchor steel, and stirrup spacing, respectively. Furthermore, φ_c, f_c', b_w and d_v are the concrete's strength factor, concrete's specified compressive strength, beam web width or diameter of the circular section or wall thickness. According to CEB-FIB [23], for beams without stirrups and for beams with stirrups, the shear strength can be obtained as follows:

$$V_{R.pred} = \begin{cases} V_{R.c} + V_{R.s} & for\ V_{R.c} + V_{R.s} < V_{R.max} \\ \max(V_{R.c}; V_{R.c}) \le V_{R.max} & for\ V_{R.c} + V_{R.s} \ge V_{R.max} \end{cases} \tag{8}$$

Here, $V_{R.pred}$, $V_{R.c}$, $V_{R.s}$ and $V_{R.max}$ are the predicted value of V_R (N), V_R attributed to concrete (N), V_R given by stirrups (N) and maximum permitted V_R (N), respectively. According to ACI 318 [21], the reinforced concrete beams' shear strength with stirrup can be calculated by using the next formulas:

$$V = \frac{A_v f_{st} d}{s} + (0.6\sqrt{f_c'} + 2500\rho_w \frac{V_u d}{M_u}) b_w d \tag{9}$$

where, A_v, f_{st}, ρ_w, s, V_u and M_u are the stirrup area (mm^2), stirrup yield stress (MPa), the spacing of transverse reinforcement (mm), factored moment, longitudinal reinforcement ratio, and factored shear force at the cross-section (N-mm), respectively.

4. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

The PSO algorithm is a swarm intelligence based technique, which optimizes a problem by executing a number of identical instructions in several iterations. Initially, some candidate solutions as particles are produced for the problem. Each particle is evaluated by an objective function that is defined for the problem. The particles can move in the search space according to simple mathematic formula aiming to find a better position. The formula uses parameters, including particle's position and velocity. Each particle maintains three values consists of the current position in the search space, velocity and best position. One of the parameters influencing the particles' movement value is the global best value that is the position of the particle, which has the best position between all the particles.

Each iteration of the PSO algorithm includes three steps: evaluate the fitness of each particle, update the velocity and position of each particle, and update individual and global best. The next formula calculates the velocity of each particle:

$$v_i(t+1) = wv_i(t) + c_1 r_1[\hat{x}_i(t) - x_i(t)] + c_2 r_2[g(t) - x_i(t)] \tag{10}$$

Here, i is the particle index. w is the inertia coefficient of velocity that is usually between 0.8 and 1.2. c_1 and c_2 are acceleration coefficients, which are often higher than zero and smaller than two. These values are usually selected close to two. r_1 and r_2 are random values, which regenerated every velocity update. These values are often between zero and one. $v_i(t)$ and $x_i(t)$ are velocity and position of the particle at time t, respectively. $\hat{x}_i(t)$ and $g(t)$ are particle's individual best solution and swarm's best solution as of time t, respectively. Lower values of the velocity speed up convergence while the higher values encourage search space exploration. The following formula updates the particle's position:

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{11}$$

5. SELECTION OF INPUT PARAMETERS AND TARGET VALUE

In this study, both the flexural and shear resistance of recycled aggregates reinforced concrete beams were assessed. For this purpose, different input parameters were employed as described below:

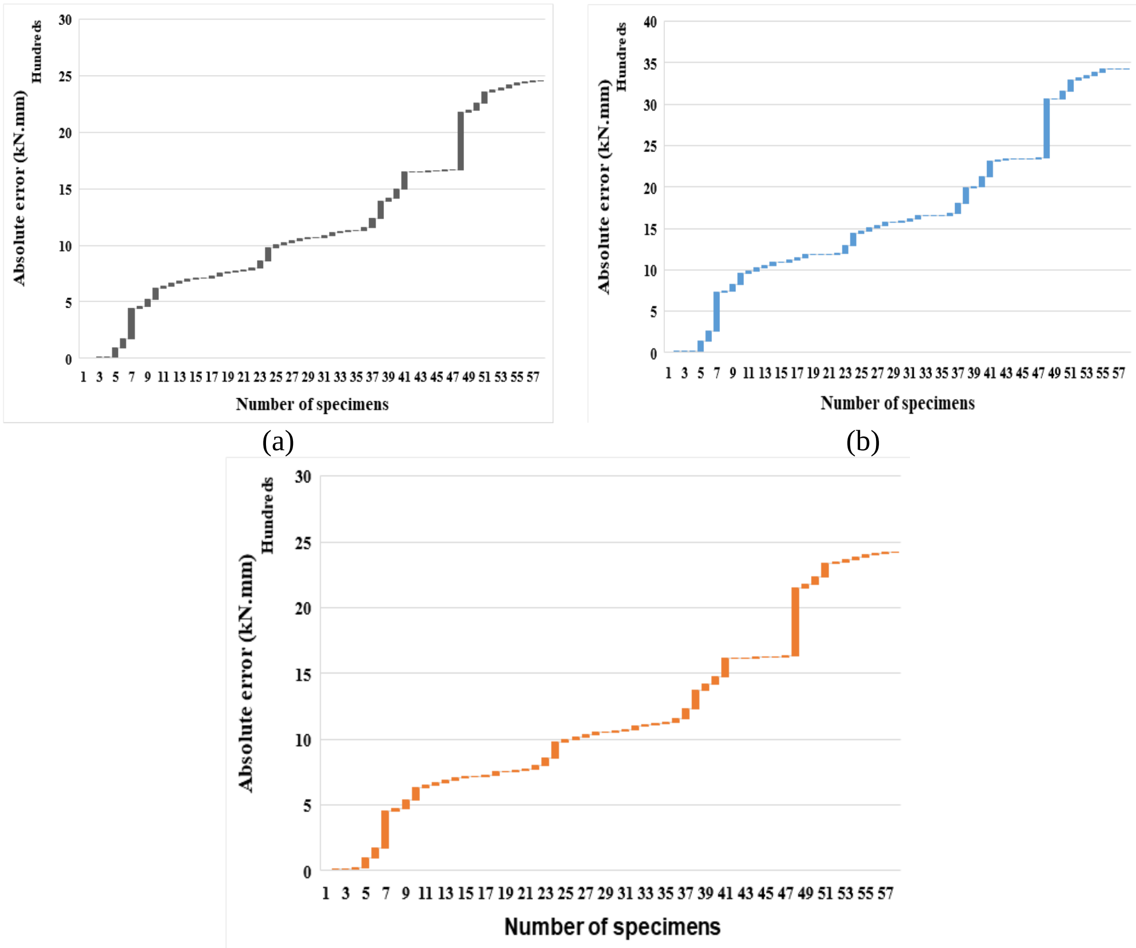
1- *Flexural strength:* recycled aggregate contents, the length of beams, cross-section width and height, concrete compressive strength, the yield strength of longitudinal rebars and the ratio of longitudinal reinforcement;

2- *Shear strength:* recycled aggregate contents, cross-section width and height, the ratio of span width to the height of specimens, the area of the shear rebars, the yield strength of longitudinal and shear reinforcements, stirrup spacing and the concrete compressive strength.

Conversely, the values of flexural and shear resistance of reinforced concrete beams containing recycled aggregates are the output consequences and the targets of this research.

6. FORMULATION TO PREDICT THE FLEXURAL RESISTANCE OF RECYCLED AGGREGATES CONCRETE BEAMS

To propose a formula for predicting the flexural performance of reinforced concrete beams containing the different value of recycled aggregates, fifty-eight experimental outcomes are utilized resulted from the investigation of Chaboki el at. [10], Arora and Singh [7], Choi and Yun [5], Azad [2], Gao and Zhang [6], Guo et al. [24], Seara-Paz et al. [3], Tošic´ et al. [8] and Tarek et al. [2]. The calculated value of the ultimate flexural resistance and the comparison between the experimental outcomes and those calculated according to the requirement of standards are represented in Tables 1 and 2, respectively, as defined in appendix A. According to these tables, the suggested equation of standards could not anticipate the flexural resistance of the recycled aggregate concrete beams considerably. Therefore, it is needed that the related equation should be corrected, which is the aim of this study. The absolute errors between the experimental outcomes and numerical consequences achieved by using the formulas of standards are illustrated in Fig. 1. This fact shows the weakness of the requirements of standards.



(c)

Fig. 1. Absolute error of flexural capacity between the numerical and experimental outcomes a) ACI b) CSA c) Eurocode

In this part, the new formula is introduced to estimate the ultimate flexural resistance of recycled aggregate concrete beams. The proposed formula for flexural is:

$$M_u = x_1 fr^{x_2} \times x_3 Ig^{x_4} \times x_5 Yt^{x_6} + x_7 \times (RCA + x_8)^{x_9} + x_{10} \tag{12}$$

The values x_1 to x_{10} are calculated by using PSO algorithm. These coefficients are constant and considered to fulfil the influence of different parameters. So, these parameters were determined using PSO. The values obtained for parameters x_i $(i\ from\ 1\ to\ 10)$ are -0.06, 0.48, -1.22, 0.65, 0.06, -0.42, 0.42, 2.87, -1.83 and -47.94, respectively. Additionally, the minimum and maximum values for each of the coefficients and power are -20 and 20, respectively. Finally, the minimum and maximum values for the constant coefficient of the Eq are -100 and 100, respectively.

By selecting this range, we have tried not to create a limit for computing of the appropriate value for the parameters. In this regard, some parameters of PSO are defined as follows:

- Maximum number of Iteration = 200, swarm size = 200, $x_1 = 1.49$, $x_2 = 1.49$ and $w = 0.72$. Mean Absolute Error (MAE) is used as the fitness function.

  Furthermore, MAE is defined as follows:

$$MAE = \frac{1}{n} \times \sum_{i=1}^{n} |m_i - (x_1 fr^{x_2} \times x_3 Ig^{x_4} \times x_5 Yt^{x_6} + x_7 \times (RCA + x_8)^{x_9} + x_{10})| \tag{13}$$

According to the introduced coefficients, the MAE of the new formula is 15.01. Also, the MAE of the proposed formula according to the introduced coefficients is 4.97e-06. The PSO algorithm is used to find the minimum value of fitness function. The results are demonstrated in Fig. 2. In addition, the ICA algorithm was employed for the proposed formula in order to predict the flexural resistance of recycled aggregate reinforced concrete. Therefore, the comparison between the results of PSO and those obtained using the ICA algorithm is represented in Fig. 3. As it is seen from this figure, the error of ICA is higher than PSO, and the accuracy of PSO to propose the flexural equation is higher than that calculated with ICA.

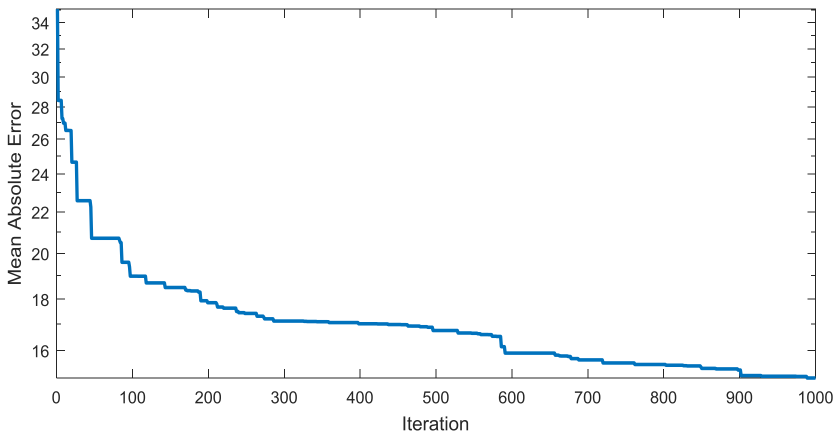


Figure 2. Mean Absolute Error of using PSO algorithm in estimating the parameters of the proposed formula for flexural resistance of recycled aggregate concrete beams

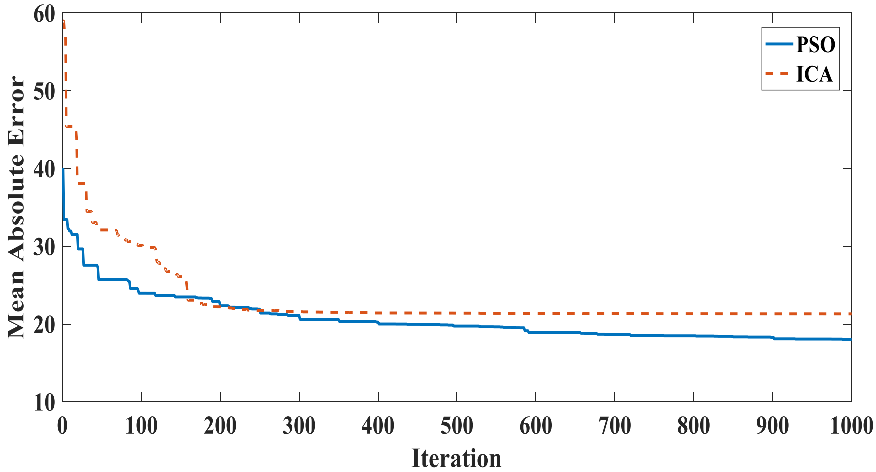
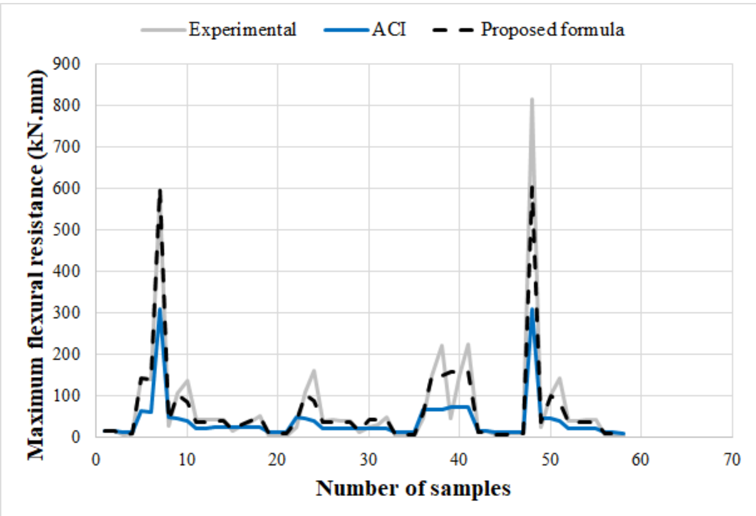
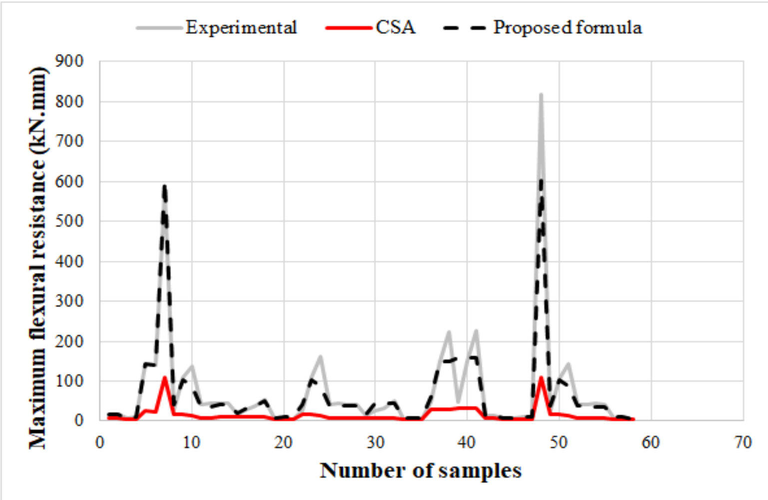


Figure 3. Comparison between the accuracy of PSO and ICA algorithm for predicting the flexural capability

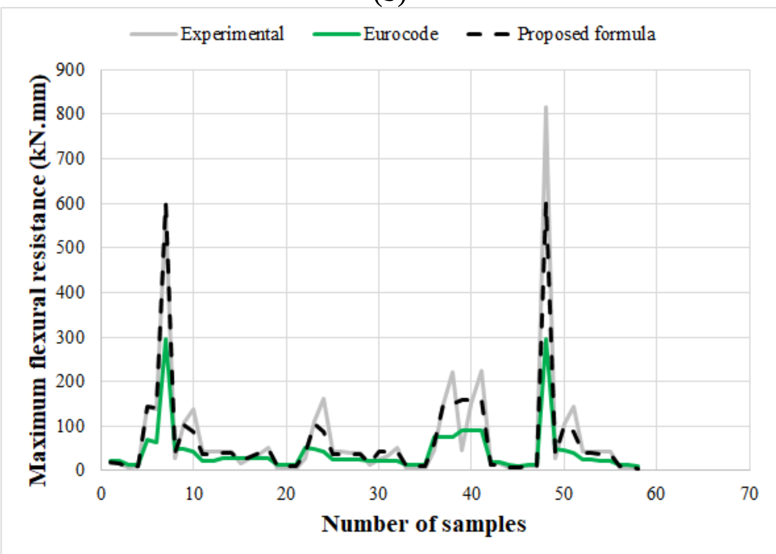
Furthermore, the experimental results are compared with those achieved numerically by the standard formula, and also by the Authors formula. The results are illustrated in Fig. 4. According to this figure, all standards could not predict the flexural resistance of recycled aggregates concrete beams adequately. On the contrary, the proposed formula has high fitting with the experimental consequences.



(a)



(b)

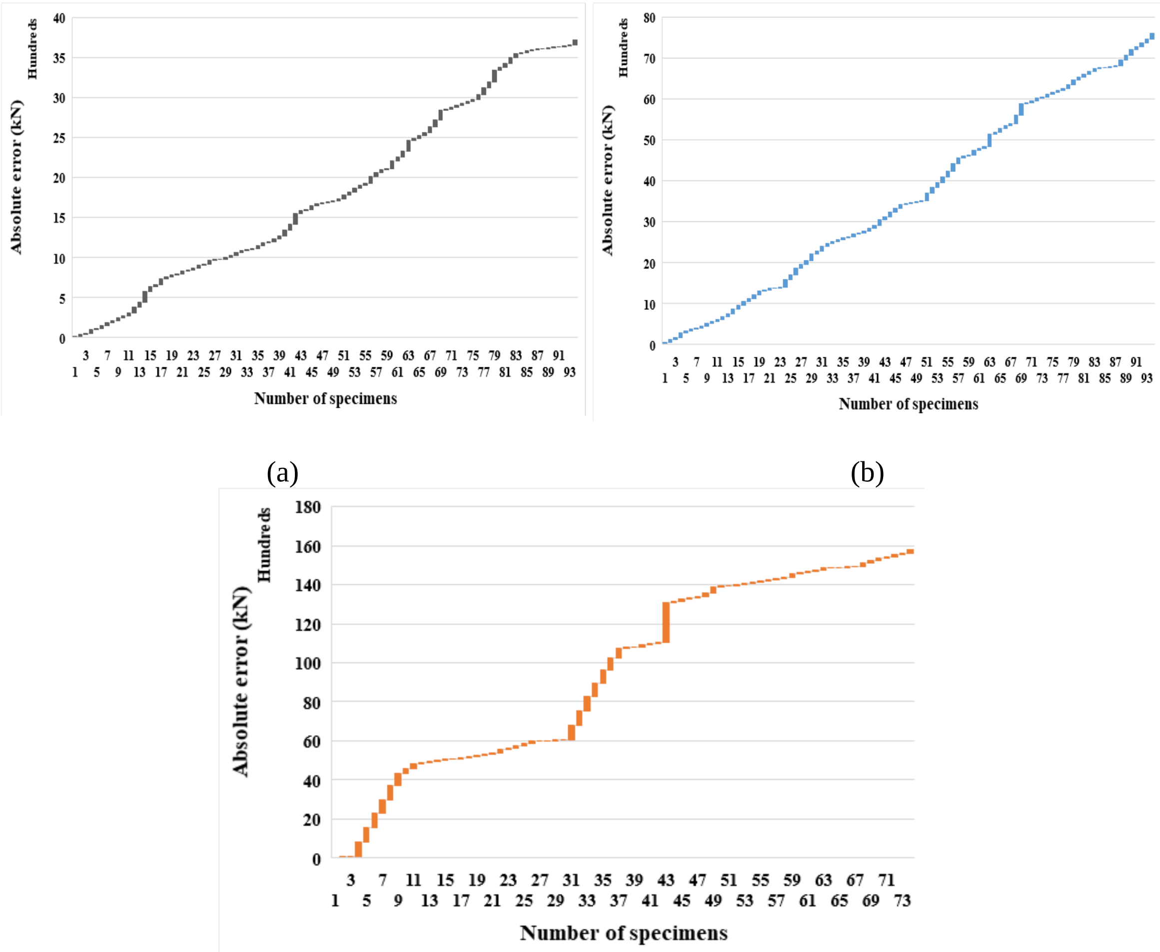


(c)

Figure 4. Comparison between the experimental flexural resistance outcomes and those obtained based on the requirements of standards and new proposed formula

7. PREDICTING THE SHEAR RESISTANCE OF RECYCLED AGGREGATES CONCRETE BEAMS

To propose a formula for forecasting the shear behavior of recycled aggregate reinforced concrete beams, ninety-four experimental consequences are employed, based on the research of Chaboki el at. [15], Han et al. [25], Gonzalez-Fonteboa and Martınez-Abella [26], Sagoe-Etxeberria et al. [27], Fathifazl et al. [28], Arezoumandi et al. [29], Sogo et al. [30] and Choi et al. [31]. Hence, the properties of specimens utilized as input values to propose an equation in this paper, and the comparisons between the collected experimental outcomes and those obtained numerically based on the requirements of standards are illustrated in Tables 3 and 4 in appendix B. According to these tables, the standard formulas could not foresee the shear strength of recycled aggregate concrete beams accurately. Therefore, their proposed equation should be improved, which is the purpose of this research. Moreover, the absolute errors between the experimental results and those obtained numerically are demonstrated in Fig. 5. This is a confirmation of the weakness of the standard requirements.



(a) (b)

(c)

Figure 5. Absolute error of shear capacity between the numerical and experimental outcomes a) ACI b) CSA c) Eurocode

According to ACI 318, the shear resistance of reinforced concrete beams with transverse reinforcement can be calculated by using the next formulas:

$$V = V_s + V_c \tag{14}$$

There are two states. When the stirrup is not utilized in specimens, the V can be calculated by the following formula:

$$V = x_1 f_c^{x_2} b_w^{x_3} d^{x_4} \tag{15}$$

Otherwise, the V is obtained by the following formula:

$$V_u = x_1 f_c^{x_2} b_w^{x_3} d^{x_4} + x_5 \frac{Asw\, f_{yt} d}{s} \tag{16}$$

The PSO algorithm is used to compute the values of x_1 to x_5. For this purpose, the fitness function is defined as follows:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\begin{Bmatrix} V_i - x_1 f_{c_i}^{x_2} b_{w_i}^{x_3} d_i^{x_4} & s = 0 \\ V_i - x_1 f_{c_i}^{x_2} b_{w_i}^{x_3} d_i^{x_4} + x_5 \frac{Asw_i f_{yt_i} d_i}{s_i} & s \neq 0 \end{Bmatrix}\right| \tag{17}$$

Fig. 5 shows the result of using PSO for calculating x_i , for i from 1 to 5. The values obtained for x_1, x_2, x_3, x_4 and x_5 are 0.0037, 0.12, 1.5, 0.68 and 0.0019, correspondingly. Furthermore, the MAE is obtained 12.14, according to the introduced coefficients. The obtained value of the error of the PSO algorithm to proposed the shear capacity formula is represented in Fig. 6. According to this figure, the error between the experimental results and those obtained numerically by using Eq. 16 is fewer, which shows the high performance of the proposed formula to forecast the shear capacity of recycled aggregates reinforced concrete beams. Additionally, the comparison between the consequences of PSO algorithm and those obtained using ICA is illustrated in Fig. 7. The PSO algorithm is compared with the ICA (Imperialist Competitive Algorithm), which is another evolutionary algorithm, for determining the coefficients of proposed equations. In ICA, each individual appears as a country. The initial population generated randomly. The cost of each individual represents the country's power. The best countries are chosen as imperialists. Also, other countries are presented as colonies. Imperialists pull the colonies in a formulize process toward themselves. In this process, the power of each country is calculated at each iteration, and new imperialists and colonies are selected. These steps are repeated until only one imperialist remain, and all the colonies converge towards it. According to Fig. 7, the error of ICA is higher than PSO, and the accuracy of PSO to propose the shear equation is higher than that calculated with ICA.

Additionally, the experimental outcomes are compared with those obtained numerically, based on the requirements of standards, and by the new suggested formula. The results are demonstrated in Fig. 8. As it is seen in this graph, standards cannot anticipate the shear performance of recycled aggregates concrete beams sufficiently, while the Authors proposed equation has high accuracy with the experimental results.

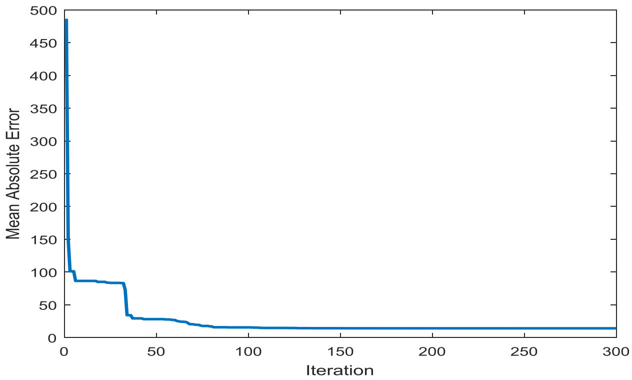


Figure 6. Mean Absolute Error of using PSO algorithm in estimating the parameters of the proposed formula for shear resistance of recycled aggregate concrete beams

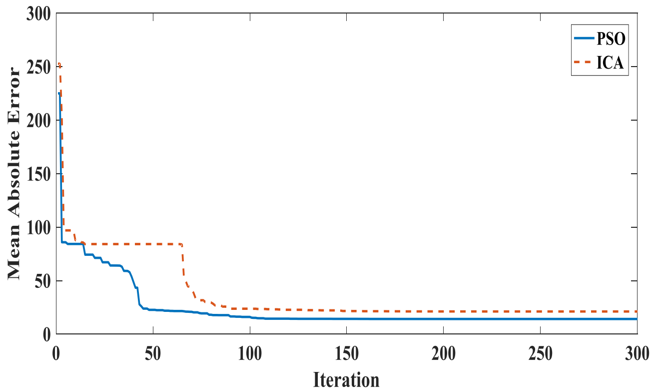
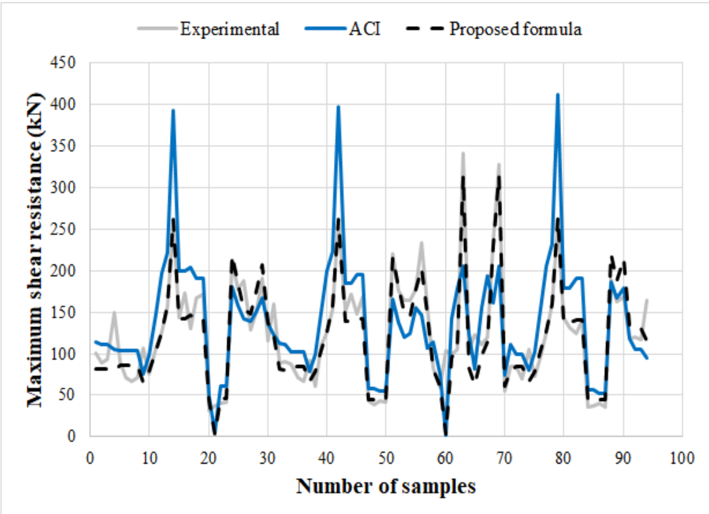
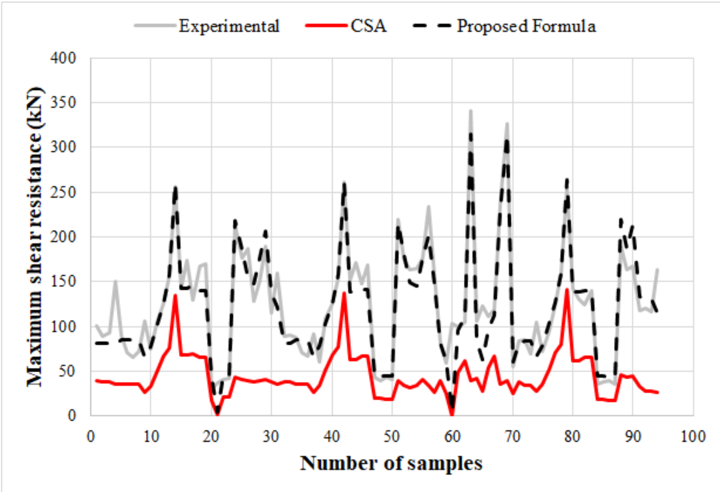


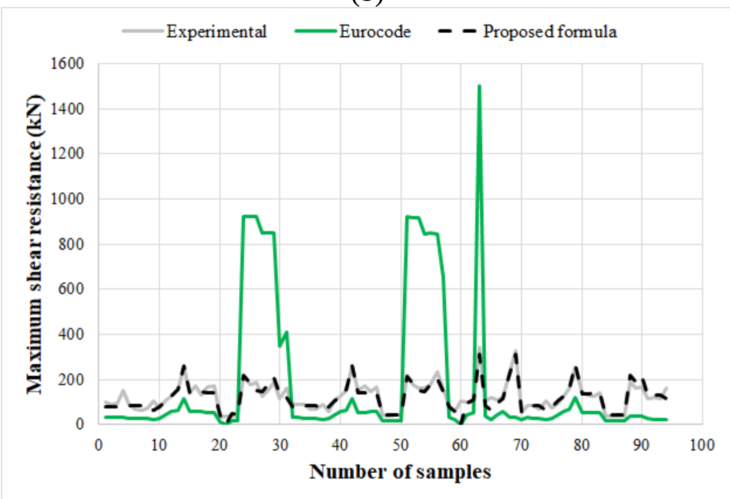
Figure 7. Comparison between the accuracy of PSO and ICA algorithm for calculating the shear capability



(a)



(b)

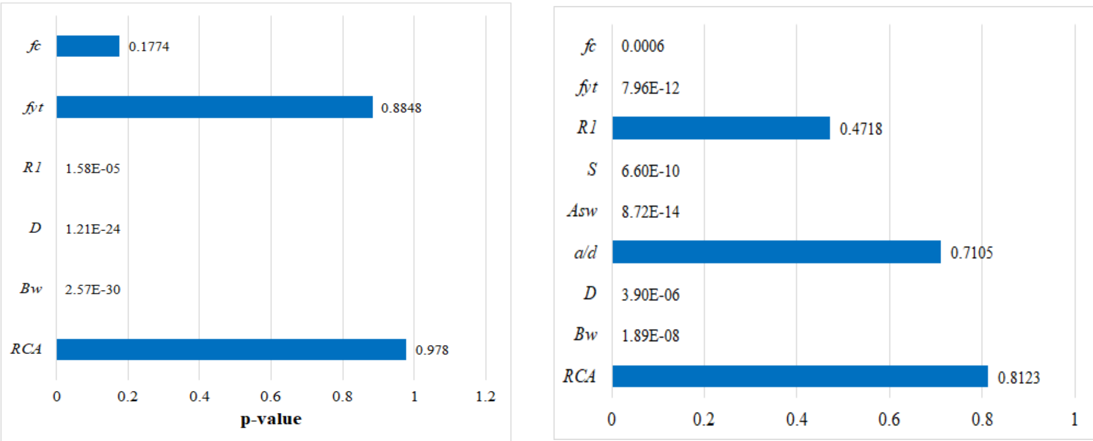


(c)

Figure 8. Comparisons between the experimental flexural resistance outcomes and those obtained based on the requirements of standards and new proposed formula

8. SENSITIVITY ANALYSIS

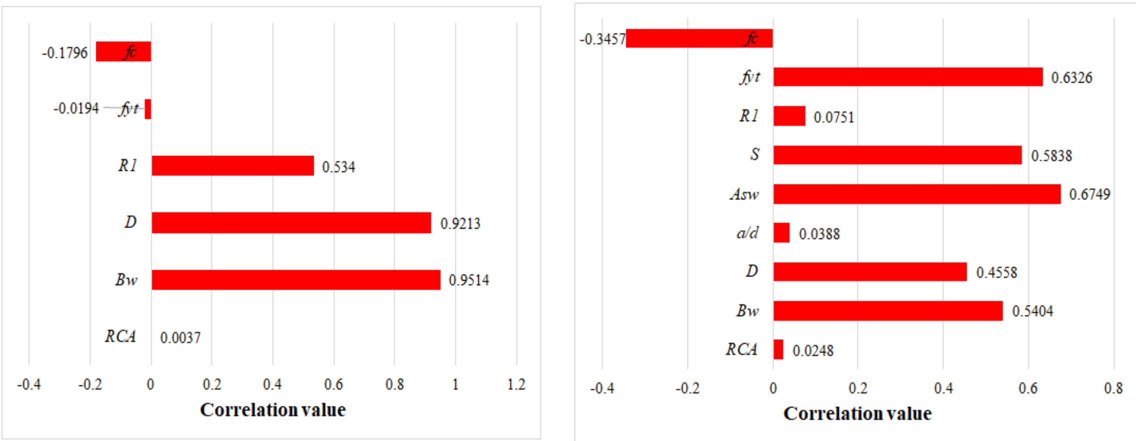
Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be divided and allocated to different sources of uncertainty in its inputs. A related practice is uncertainty analysis, which has a greater focus on uncertainty quantification and propagation of uncertainty; ideally, uncertainty and sensitivity analysis should be run in tandem. In reviewing the literature on recycled aggregates concrete beam, data were composed of laboratory experiments. The gathered parameters included relative maximum shear resistance and bending capacity. The initial statistical model was developed under the assumption that all parameters affect concrete mixture and then, considering all parameters as input variables and an output variable, a multiple regression analysis was performed to measure the correlation between parameters includes compressive strength of the concrete, the ratio of the longitudinal reinforcement, the cross-section area of the specimens, length of the beam, yield resistance of the rebars, transverse reinforcement spacing and the ratio of the span width to height of the specimens. Once the initial analysis was completed, the significance of the input variables was evaluated by testing the null hypothesis via comparison of p-values [32]. The bar diagrams in Fig. 9 compare p-values for the input parameters collected from the literature and used to propose the maximum flexural and shear capacity of recycled aggregates reinforced concrete beams. It should be stated that the p-value is computed by transforming the correlation to create a t statistic having n-2 degrees of freedom, where n is the number of rows of X. The confidence bounds are based on an asymptotic normal distribution of 0.5*log((1+R)/(1-R)), with an approximate variance equal to 1/(n-3).



(a) (b)

Figure 9. Global sensitivity analysis of factors affecting concrete beam's behavior according to p-value a) flexural resistance and b) shear strength

According to Fig. 9, the parameters with a low p-value have a high influence on the output target value. As it is seen from this figure, concrete compressive strength, the longitudinal rebars ratio, effective cross-section depth and height have more influence on the maximum flexural resistance compared to the recycled coarse aggregates' contents. On the other hand, the influence of concrete compressive strength, transverse rebars yield strength, stirrup spacing, stirrup crass-section area, effective cross-section depth and height have a substantial effect of the shear capacity of recycled aggregates reinforced concrete beams relative to the value of recycled coarse aggregates, which indicates a strong presumption against the null hypothesis. Additionally, the correlation between different input parameters influences the behavior of RC beams containing recycled coarse aggregates was assessed, as demonstrated in Fig. 10. The steel and concrete materials; however, the recycled coarse aggregates have a considerable correlation with other parameters of concrete particles so that the influence parameters affect the flexural strength of RC beams (Fig. 10a). In addition, the same effective influence of recycled coarse aggregates on the shear capability of RC beams was observed, as represented in Fig. 10b. Therefore, recycled coarse aggregate contents are the important property should be considered in the requirements that should be considered to predict the flexural and shear resistance of reinforced concrete beams having recycled coarse aggregates. Furthermore, these results indicate the weakness of the requirement proposed by standards. Moreover, the experimental results carried out by previous studies show the importance of improving the relations of standards when recycled coarse aggregates are utilized [10, 15, 33].



(a) (b)

Figure 10. Correlation value between factors affecting concrete beam's behavior according to p-value a) flexural resistance and b) shear strength

9. IMPROVING THE CURRENT STANDARD

In this section, in addition to proposed new formulas to predict the flexural and shear behavior of recycled aggregates concrete beams, SOP was employed to improve the current equation of ACI. For this aim, the following formula was developed:

$$M_{ult.ACI} = X_1 A'_s f_y (d - d') + X_2 (A_s - A'_s) f_y \left(d - \frac{(A_s - A'_s) f_y}{2 \times 0.85 f_c'^{X3} b}\right) \quad (18)$$

The values obtained for x_1, x_2 and x_3 are 3×10^{-4}, 0.82 and 2×10^{-3}, correspondingly. Furthermore, the MAE is utilized to reduce the error and increase the accuracy of ACI's model according to the introduced coefficients. The compression between the new proposed formula and the developed equation of ACI to estimate the flexural capacity of recycled aggregates reinforced concrete beams is represented in Fig. 11. According to this figure, the error between the new presented formula and that developed based on the requirement of ACI is significant, and developing the current standards' formula is not a good idea. Therefore, presenting a new equation in importance, which contains more variable such as recycled aggregates contents.

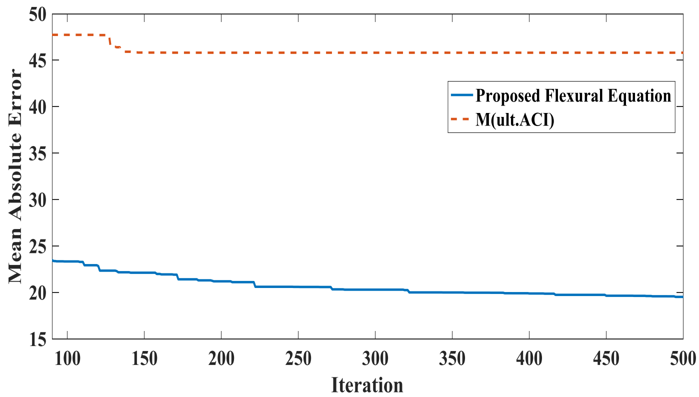


Figure 11. Comparison between the error of the new proposed formula and the developed equation of ACI to predict the flexural strength

Furthermore, the current equation proposed by ACI was developed using SOP in order to anticipate the shear capacity of recycled aggregates reinforced concrete beams. This formula was developed as below:

$$V_r = X_1 \varphi_c \lambda \beta \sqrt{f_c'}^{X_2} b_w d_v + X_3 \frac{\varphi_c A_v f_y d_v}{S} \tag{19}$$

The values obtained for x_1, x_2 *and* x_3 are 7.8×10^{-6}, 2×10^{-9} and 2.13, respectively. Additionally, the MAE is employed to raise the accuracy of ACI's model according to the introduced coefficients. As a result, the compression between the new proposed equation and the developed equation of ACI to forecast the shear strength of recycled aggregates reinforced concrete beams is represented in Fig. 12. As it is seen from this figure, the error between the new presented equation and that developed ACI's equation is major, and developing the current standards' formula is not a good way. Consequently, presenting a new equation is necessary, which contains more variable such as the replacement value of recycled aggregates.

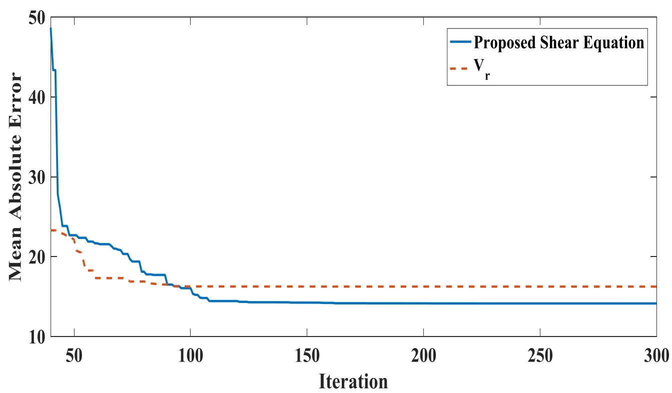


Figure 12. Comparison between the error of the new proposed formula and the developed equation of ACI to predict the flexural strength

10. CONCLUSION

In this study, the new formulas are proposed to predict the flexural and shear resistance of the recycled coarse aggregated reinforced concrete beams. For this aim, 152 experimental outcomes were utilized, and PSO algorithm was employed to establish a new equation. To study very general cases, the compressive strength of concrete, the ratio of the longitudinal reinforcement, the cross-section area of the specimens, length of the beam, yield resistance of the rebars, transverse reinforcement spacing and the ratio of the span width to the height of specimens were the input data. According to the obtained results, the PSO algorithm was the powerfully useful scheme to find new formulas, which satisfy the experimental consequences. It is found that the suggested equations by ACI 318, CSA and Eurocode could not anticipate the shear accurately and bending strength of reinforced concrete beams containing recycled coarse aggregates. Alternatively, the proposed relationship presented in this study can forecast the value of both shear and flexural capacity of recycled aggregate concrete beams more correctly. In fact, the Author formula led to the smallest error, compared with those achieved experimentally.

Funding: Any company did not fund this study.

Conflict of Interest: The authors declare that they have no conflict of interest.

APPENDIX A

Table 1. Specimens' characteristics and input data for flexural Performance

Specimens	Recycled coarse aggregates content (%)	b_w (mm)	d (mm)	ρ_1	f_{yt} (MPa)	f_c (MPa)	M_u **(kN.mm)**
1	0	150	160	1.06	331	57	**15**
2	0	150	160	1.06	331	55.3	**15.3**
3	0	150	160	0.59	331	30.6	**8**
4	0	150	160	0.59	331	32.5	**9.1**
5	0	200	304	1.99	420	37.1	**142.7**
6	0	200	304	1.99	420	33.8	**139.1**
7	0	400	525	2.34	380	26.9	**578.9**
8	0	200	268	0.28	640	35	**28.4**
9	0	200	263	1.46	550	35	**108.6**
10	0	200	244	2.54	550	35	**137.6**
11	0	150	200	1.3	572	38.6	**42.6**
12	0	150	200	1.3	572	38.6	**43.1**
13	0	150	200	1.3	572	46.5	**43.8**
14	0	150	200	1.3	572	46.5	**43.8**
15	0	135	230	0.5	377	38.6	**15.9**
16	0	135	230	1	408	38.6	**28.2**
17	0	135	230	1.5	389	38.6	**36.9**
18	0	135	230	1.8	410	38.6	**52.8**
19	0	150	157	0.02	371	35	**5**
20	0	150	157	0.02	371	37.3	**5**

Specimens	Recycled coarse aggregates content (%)	b_w (mm)	d (mm)	ρ_1	f_{yt} (MPa)	f_c (MPa)	M_u **(kN.mm)**
21	0	150	157	0.02	371	36	**5**
22	50	200	268	0.28	640	35.4	**27**
23	50	200	263	1.46	550	35.4	**110.6**
24	50	200	244	2.54	550	35.4	**160.4**
25	50	150	200	1.3	572	40	**41.8**
26	50	150	200	1.3	572	40	**43.1**
27	50	150	200	1.3	572	39.3	**41.3**
28	50	150	200	1.3	572	39.3	**41.3**
29	50	135	230	0.5	377	29	**13.6**
30	50	135	230	1	408	29	**24.4**
31	50	135	230	1.5	389	29	**32.8**
32	50	135	230	1.8	410	29	**50.5**
33	50	150	157	0.02	371	35	**4.5**
34	50	150	157	0.02	371	35	**5**
35	50	150	157	0.02	371	35	**5.5**
36	63.5	200	304	0.49	420	41.6	**46**
37	63.5	200	304	1.99	420	41.6	**149.2**
38	63.5	200	304	3.26	420	41.6	**221.9**
39	74.3	200	304	0.49	420	49.1	**46.7**
40	74.3	200	304	1.99	420	49.1	**150.2**
41	74.3	200	304	3.26	420	49.1	**225.2**
42	100	150	160	1.06	331	46.5	**14.8**
43	100	150	160	1.06	331	46.6	**15.1**
44	100	150	160	0.59	331	30.4	**8.5**
45	100	150	160	0.59	331	28.4	**8.9**
46	100	150	160	0.59	331	34.5	**9.3**
47	100	150	160	0.59	331	31.8	**9.5**
48	100	400	525	2.34	380	26.9	**817.6**
49	100	200	268	0.28	640	34	**26.8**
50	100	200	263	1.46	550	34	**105.4**
51	100	200	244	2.54	550	34	**142.6**
52	100	150	200	1.3	572	43.8	**41.7**
53	100	150	200	1.3	572	43.8	**41.7**
54	100	150	200	1.3	572	38.5	**44.1**
55	100	150	200	1.3	572	38.5	**42.5**
56	100	150	157	0.02	371	39.3	**6**
57	100	150	157	0.02	371	37.3	**6.5**
58	100	150	157	0.02	371	25.6	**5**

Table 2. Compression the values of flexural capacity

specimens	**Experimental (kN.mm)**	ACI (kN.mm) [21]	CSA (kN.mm) [22]	EuroCode 2 (kN.mm) [23]
1	**15**	17.8	8.3	21.9
2	**15.3**	17.5	8.1	21.2
3	**8**	13.0	4.5	11.8
4	**9.1**	13.4	4.8	12.5
5	**142.7**	63.4	25	68.6
6	**139.1**	60.5	22.8	62.5
7	**578.9**	310.2	110.4	296.6
8	**28.4**	48.4	16.5	50.3
9	**108.6**	46.7	16.6	48.4
10	**137.6**	40.6	14.3	41.7
11	**42.6**	22.0	7.9	23.2
12	**43.1**	22.0	7.9	23.2
13	**43.8**	24.2	9.5	27.9
14	**43.8**	24.2	9.5	27.9
15	**15.9**	25.7	10.3	27.6
16	**28.2**	25.7	10.1	27.6
17	**36.9**	25.7	10.2	27.6
18	**52.8**	25.7	10.1	27.6
19	**5**	13.4	4.8	12.9
20	**5**	13.9	5.2	13.8
21	**5**	13.6	5	13.3
22	**27**	48.7	16.7	50.9
23	**110.6**	46.9	16.8	49
24	**160.4**	40.8	14.4	42.2
25	**41.8**	22.4	8.1	24
26	**43.1**	22.4	8.1	24
27	**41.3**	22.2	8	23.6
28	**41.3**	22.2	8	23.6
29	**13.6**	22.3	7.7	20.7
30	**24.4**	22.3	7.6	20.7
31	**32.8**	22.3	7.7	20.7
32	**50.5**	22.3	7.6	20.7
33	**4.5**	13.4	4.8	12.9
34	**5**	13.4	4.8	12.9
35	**5.5**	13.4	4.8	12.9
36	**46**	67.1	28.1	76.9
37	**149.2**	67.1	28.1	76.9
38	**221.9**	67.1	28.1	76.9
39	**46.7**	72.9	33.1	90.8
40	**150.2**	72.9	33.1	90.8
41	**225.2**	72.9	33.1	90.8
42	**14.8**	16.0	6.8	17.9

43	**15.1**	16.0	6.8	17.9
44	**8.5**	12.9	4.4	11.7
45	**8.9**	12.5	4.2	10.9
46	**9.3**	13.8	5.1	13.2
47	**9.5**	13.3	4.7	12.2
48	**817.6**	310.2	110.4	296.6
49	**26.8**	47.7	16	48.8
50	**105.4**	46.0	16.1	47
51	**142.6**	39.9	13.9	40.5
52	**41.7**	23.4	8.9	26.3
53	**41.7**	23.4	8.9	26.3
54	**44.1**	21.9	7.8	23.1
55	**42.5**	21.9	7.8	23.1
56	**6**	14.2	5.4	14.5
57	**6.5**	13.9	5.2	13.8
58	**5**	11.5	3.5	9.5

APPENDIX B

Table 3. Specimens' properties and input data for shear behavior

Specimens	Recycled coarse aggregates content (%)	b_w (mm)	d (mm)	a/d	A_{sw} (mm^2)	S (mm)	ρ_1	f_{yt} (MPa)	f_c (MPa)	V_u (kN)
1	0	200	303	3.3	0	0	2.98	0	41.9	**100.5**
2	0	200	303	3.3	0	0	2.98	0	40.2	**88.9**
3	0	200	309	2.6	0	0	1.62	0	38.8	**92.8**
4	0	200	309	2.6	0	0	1.62	0	34.4	**150**
5	0	200	360	2.5	0	0	1.61	0	24.7	**90.7**
6	0	200	360	3.25	0	0	1.61	0	24.7	**71.1**
7	0	200	360	2.5	0	0	0.53	0	24.7	**66.2**
8	0	200	360	2.5	0	0	0.83	0	24.7	**72**
9	0	200	235	4.2	0	0	4.09	0	30.8	**106.3**
10	0	200	300	2.5	0	0	1.94	0	31.8	**75.5**
11	0	200	450	2.5	0	0	1.93	0	31.8	**106.9**
12	0	200	600	2.5	0	0	1.94	0	31.8	**125.9**
13	0	300	450	2.5	0	0	2	0	31.8	**156.7**
14	0	400	600	2.5	0	0	1.94	0	31.8	**256.4**
15	0	300	375	3.2	0	0	2.03	0	37.3	**143.2**
16	0	300	375	3.2	0	0	2.71	0	37.3	**173.5**
17	0	300	400	3	0	0	1.27	0	34.2	**129.9**
18	0	300	375	3.2	0	0	2.03	0	34.2	**167**
19	0	300	375	3.2	0	0	2.71	0	34.2	**170.8**
20	0	150	200	3.8	0	0	1.3	0	32.6	**31.1**
21	0	15	200	3.8	0	0	1.3	0	32.6	**36.9**
22	0	150	200	3.8	0	0	1.3	0	50.3	**40.4**
23	0	150	200	3.8	0	0	1.3	0	50.3	**42.3**
24	0	200	303	3.3	57	130	2.71	544	37.3	**213**

25	0	200	303	3.3	57	170	1.27	544	34.2	**177**
26	0	200	303	3.3	57	240	2.03	544	34.2	**187.5**
27	0	200	303	3.3	57	240	2.71	500	34.2	**128**
28	0	200	303	3.3	57	170	1.3	500	32.6	**150.8**
29	0	200	303	3.3	57	130	1.3	500	32.6	**190.3**
30	0	200	250	3.3	57	100	1.3	234	50.3	**115.5**
31	0	200	235	4.2	57	150	1.3	300	50.3	**159.9**
32	50	200	303	3.3	0	0	2.98	0	41.3	**89**
33	50	200	303	3.3	0	0	2.98	0	39.7	**90.6**
34	50	200	360	2.5	0	0	1.61	0	24.1	**87.9**
35	50	200	360	3.25	0	0	1.61	0	24.1	**71.6**
36	50	200	360	2.5	0	0	0.83	0	24.1	**67.1**
37	50	200	235	4.2	0	0	4.09	0	33.4	**91.8**
38	50	200	300	2.5	0	0	1.94	0	32.6	**60.6**
39	50	200	450	2.5	0	0	1.93	0	32.6	**108.9**
40	50	200	600	2.5	0	0	1.94	0	32.6	**126.1**
41	50	300	450	2.5	0	0	2	0	32.6	**154.2**
42	50	400	600	2.5	0	0	1.94	0	32.6	**261.5**
43	50	300	375	3.2	0	0	2.03	0	32.1	**151.3**
44	50	300	375	3.2	0	0	2.71	0	32.1	**171.8**
45	50	300	375	3.2	0	0	2.03	0	35.5	**148.6**
46	50	300	375	3.2	0	0	2.71	0	35.5	**168.7**
47	50	150	200	3.8	0	0	1.3	0	43.6	**44**
48	50	150	200	3.8	0	0	1.3	0	43.6	**39.1**
49	50	150	200	3.8	0	0	1.3	0	40.2	**43.7**
50	50	150	200	3.8	0	0	1.3	0	40.2	**41.2**
51	50	200	303	3.3	57	130	2.71	544	28	**220**
52	50	200	303	3.3	57	170	1.27	544	22	**176**
53	50	200	303	3.3	57	240	2.03	544	21	**164**
54	50	200	303	3.3	57	240	2.71	500	25	**164.3**
55	50	200	303	3.3	57	170	1.3	500	35	**177**
56	50	200	303	3.3	57	130	1.3	500	21	**233.6**
57	50	200	235	235	57	150	1.3	500	21	**156.9**
58	63.5	200	305	3.9	0	0	2.46	0	41.6	**83.2**
59	63.5	200	201	2.7	0	0	1.99	0	41.6	**59.3**
60	63.5	200	3.9	2.6	0	0	1.62	0	41.6	**103.9**
61	63.5	200	381	2.7	0	0	1.83	0	41.6	**99.5**
62	63.5	200	476	2.7	0	0	1.68	0	41.6	**104.6**
63	63.5	200	301	2.7	157	200	1.3	530	21	**341**
64	74.3	200	305	3.9	0	0	2.46	0	49.1	**105.6**
65	74.3	200	201	2.6	0	0	1.99	0	49.1	**122.6**
66	74.3	200	381	2.7	0	0	1.83	0	49.1	**111.7**
67	74.3	200	476	2.7	0	0	1.68	0	49.1	**119.6**
68	74.3	200	301	2.7	101	200	1.3	530	21	**235**
69	74.3	200	301	2.7	157	200	1.3	530	21	**327**
70	100	170	270	3	0	0	1.1	0	31.2	**55.1**
71	100	200	303	3.3	0	0	2.98	0	39.8	**84**
72	100	200	360	2.5	0	0	1.61	0	22.6	**84.8**
73	100	200	360	2.5	0	0	0.83	0	22.6	**70.1**
74	100	200	235	4.2	0	0	4.09	0	34.5	**104.8**
75	100	200	300	2.5	0	0	1.94	0	34.9	**72.9**

76	100	200	450	2.5	0	0	1.93	0	34.9	**96.4**
77	100	200	600	2.5	0	0	1.94	0	34.9	**125.1**
78	100	300	450	2.5	0	0	2	0	34.9	**159.8**
79	100	400	600	2.5	0	0	1.94	0	34.9	**256.6**
80	100	300	375	3.2	0	0	2.03	0	30	**143.2**
81	100	300	375	3.2	0	0	2.71	0	30	**131.4**
82	100	300	375	3.2	0	0	2.03	0	34.1	**124.1**
83	100	300	375	3.2	0	0	2.71	0	34.1	**140.3**
84	100	150	200	3.8	0	0	1.3	0	41.4	**36.4**
85	100	150	200	3.8	0	0	1.3	0	41.4	**38**
86	100	150	200	3.8	0	0	1.3	0	35.7	**39.9**
87	100	150	200	3.8	0	0	1.3	0	35.7	**36.1**
88	100	200	303	3.3	57	130	2.98	544	41.9	**189.5**
89	100	200	303	3.3	57	170	2.98	544	40.2	**163**
90	100	200	303	3.3	101	240	2.98	544	38.8	**168**
91	100	200	250	3.2	57	100	2.98	234	34.4	**118**
92	100	200	250	3.2	57	100	2.98	234	24.7	**120.5**
93	100	200	250	3.2	57	100	2.98	234	24.7	**116.5**
94	100	200	235	4.2	57	150	2.98	300	24.7	**163.4**

Table 4. Compression the values of shear capacity

Specimens	**Experimental (kN)**	ACI (kN) [21]	CSA (kN) [22]	EuroCode 2 (kN) [23]
1	**100.5**	113.8	39.2	33.3
2	**88.9**	111.4	38.4	32.7
3	**92.8**	111.6	38.5	32.7
4	**150**	105.1	36.2	30.8
5	**90.7**	103.8	35.8	30.4
6	**71.1**	103.8	35.8	30.4
7	**66.2**	103.8	35.8	30.4
8	**72**	103.8	35.8	30.4
9	**106.3**	75.6	26.1	22.2
10	**75.5**	98.1	33.8	28.8
11	**106.9**	147.2	50.8	43.1
12	**125.9**	196.2	67.7	57.5
13	**156.7**	220.8	76.1	64.7
14	**256.4**	392.5	135.3	115
15	**143.2**	199.3	68.7	58.4
16	**173.5**	199.3	68.7	58.4
17	**129.9**	203.5	70.2	59.7
18	**167**	190.8	65.8	55.9
19	**170.8**	190.8	65.8	55.9
20	**31.1**	49.7	17.1	14.6
21	**36.9**	5	1.7	1.5
22	**40.4**	61.7	21.3	18.1
23	**42.3**	61.7	21.3	18.1
24	**213**	179.6	44.2	924

25	**177**	158	41	922.7
26	**187.5**	141.9	39.4	922.7
27	**128**	138.8	39	850.5
28	**150.8**	151.1	39.7	849.8
29	**190.3**	166.8	41.2	849.8
30	**115.5**	136.2	38.8	346.9
31	**159.9**	123.5	36	410.1
32	**89**	112.9	38.9	33.1
33	**90.6**	110.7	38.2	32.5
34	**87.9**	102.5	35.3	30
35	**71.6**	102.5	35.3	30
36	**67.1**	102.5	35.3	30
37	**91.8**	78.8	27.2	23.1
38	**60.6**	99.3	34.3	29.1
39	**108.9**	149	51.4	43.7
40	**126.1**	198.7	68.5	58.2
41	**154.2**	223.5	77.1	65.5
42	**261.5**	397.4	137	116.5
43	**151.3**	184.8	63.7	54.2
44	**171.8**	184.8	63.7	54.2
45	**148.6**	194.4	67	57
46	**168.7**	194.4	67	57
47	**44**	57.4	19.8	16.8
48	**39.1**	57.4	19.8	16.8
49	**43.7**	55.2	19	16.2
50	**41.2**	55.2	19	16.2
51	**220**	165.3	39.3	919.8
52	**176**	137.7	34	916.7
53	**164**	119.7	31.7	916.2
54	**164.3**	123.9	33.9	846.1
55	**177**	154.8	40.9	850.8
56	**233.6**	147	34.4	844
57	**156.9**	107.1	26	654.6
58	**83.2**	114.1	39.3	33.4
59	**59.3**	75.2	25.9	22
60	**103.9**	1.5	0.5	0.4
61	**99.5**	142.5	49.1	41.8
62	**104.6**	178.1	61.4	52.2
63	**341**	205.2	40.1	2402.8
64	**105.6**	124	42.7	36.3
65	**122.6**	81.7	28.2	23.9
66	**111.7**	154.8	53.4	45.4
67	**119.6**	193.5	66.7	56.7
68	**235**	160.6	35.6	31.1
69	**327**	205.2	40.1	35.3
70	**55.1**	74.4	25.6	21.8

71	**84**	110.9	38.2	32.5
72	**84.8**	99.3	34.2	29.1
73	**70.1**	99.3	34.2	29.1
74	**104.8**	80.1	27.6	23.5
75	**72.9**	102.8	35.4	30.1
76	**96.4**	154.2	53.2	45.2
77	**125.1**	205.6	70.9	60.3
78	**159.8**	231.3	79.8	67.8
79	**256.6**	411.2	141.8	120.5
80	**143.2**	178.7	61.6	52.4
81	**131.4**	178.7	61.6	52.4
82	**124.1**	190.5	65.7	55.8
83	**140.3**	190.5	65.7	55.8
84	**36.4**	56	19.3	16.4
85	**38**	56	19.3	16.4
86	**39.9**	52	17.9	15.2
87	**36.1**	52	17.9	15.2
88	**189.5**	186	46.5	40.2
89	**163**	166.7	43.9	37.9
90	**168**	178.8	44.7	38.7
91	**118**	118.4	32.7	28.1
92	**120.5**	105.4	28.2	24.3
93	**116.5**	105.4	28.2	24.3
94	**163.4**	94.5	26	22.4

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