Optimization of concrete mix design using genetic algorithms

B-Tech Project - I

Submitted by

Islavath Mohan Naik
21CE31006

Under the supervision of
Dr. Amit Shaw

Department of Civil Engineering

Indian Institute of Technology, Kharagpur
November, 2024

DECLARATION BY THE STUDENT

I hereby declare that

(a) The work contained in this report has been done by me under the guidance of my supervisor.

(b) The work has not been submitted to any other Institute for any degree or diploma.

(c) I have followed the norms and guidelines given in the Ethical Code of Conduct of the Institute.

(d) Whenever I have used materials (data, theoretical analysis, figures and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references. Further, I have taken permission from the copyright owners of the sources, whenever necessary.

Date:
Place: IIT Kharagpur

Islavath Mohan Naik
Roll no: 21CE31006

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
KHARAGPUR-721302, INDIA

CERTIFICATE

This is to certify that the project entitled " **Optimization of concrete mix design using genetic algorithms**" is a bonafide record of authentic work carried out by Islavath Mohan Naik (21CE31006) under my supervision and guidance for the course BTech Project - 1 (CE47005) in the Department of Civil Engineering at the Indian Institute of Technology Kharagpur.

Date:
Place: IIT Kharagpur

Amit Shaw
Professor
Department of Civil Engineering
Indian Institute of Technology
Kharagpur

ACKNOWLEDGEMENT

I sincerely thank my project supervisor, Dr. Amit Shaw, Professor in the Department of Civil Engineering at IIT Kharagpur, for his unwavering support and valuable guidance. His insightful comments and encouragement were pivotal in keeping me motivated and transforming this project into a profound learning experience. The present work would not have been possible without his active interest and continuous guidance.

I wish to express my deep gratitude to my parents for their unwavering love and support throughout this academic journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Flexibility of making concrete with natural resources, easiness in shaping and dimension and cost of production has made ‘Concrete’ the 2nd biggest consumed source on earth. Concrete Mix design is a lengthy process and it requires experience to determine the accurate mix proportions. Concrete mix design plays a major role in civil engineering. It forms the first and most important step before starting any project. The concrete mix obtained should be economical. Optimization technique is one of the best methods to design a concrete mix. It saves time as well as results in a good mix. Optimization technique like ‘Genetic Algorithm’ in MATLAB is highly useful in designing a concrete mix. It is used for optimizing Abrams’s water-cement law to find optimum water/cement ratio and the corresponding strength value.

Different optimisation techniques like Genetic Algorithms (GA), Artificial Neural Networks etc. are being used to derive reliable quality solutions for optimization. Genetic Algorithms is a search based optimization technique initially originated based on the principles of Genetics and Natural Selection. Such techniques are useful for determining optimal or near-optimal solutions to difficult problems in time efficient manner.

Concrete mix design forms the basic and most important step in construction. It is that stage in construction which defines the quality of concrete and which affects the quality of the structure. Concrete having good feature increases its characteristics like durability and strength. The concrete properties definitely enhanced through proper design mix which is made from appropriate constituents in respective proportions. To obtain perfect concrete mix meeting the desirable characteristics, appropriate proportioning of materials is required. Major factors affecting Concrete Mix Design are: Grade of Concrete, Type of Cement, Aggregate size, Water to Cement ratio and Workability.

1.1 Objective and Scope

The main objective of this study is to develop optimized concrete mixes for grades M20, M25, and M30 using the Genetic Algorithm (GA). The optimization process focuses on achieving an efficient mix design that adheres to strength, workability, and durability standards while minimizing material costs. A MATLAB-based code is developed to automate the concrete mix design, integrating Abrams’ water-cement law as the governing principle, given that the water-to-cement (w/c) ratio significantly influences the performance of concrete. By incorporating GA, the study aims to identify the best combination of mix parameters, such as cement, water, fine aggregate, and coarse aggregate proportions, to meet the targeted grade requirements.

Genetic Algorithm, inspired by the principles of natural selection and evolution, enables iterative optimization through crossover, mutation, and selection processes. The study uses GA to optimize the w/c ratio and other parameters to meet the strength criteria specified in Indian Standards (IS 10262 and IS 456). The optimized parameters obtained through GA are then integrated into the mix design code, enabling the creation of concrete mixes that balance strength, workability, and cost-effectiveness. This approach ensures consistency, accuracy, and reduced reliance on trial-and-error methods in traditional mix design. The scope of this study extends to providing a framework for computational mix design optimization that can be adapted for other grades or performance-based requirements, contributing to sustainable and efficient concrete production.

2. LITERATURE REVIEW

Earlier studies attempted the use of computer programming in the mix design of high strength concrete. Murthy et al. (2013) [1] have presented a methodology for mix design of high strength concrete. The developed program and the compared outcomes with the manual output and verified with the previous studies. The authors concluded that the program produced precise and consistent output within short duration and optimum mix proportions are obtained using silica fume as partial replacement of cement. Park (2013) [2] proposed a design method for the mix proportion of recycled aggregate based concrete through various fitness functions. The concept of multi criteria optimization, in Genetic Algorithm is applied for mix design, which resulted in optimized mix proportions.

Later researchers started using MATLAB and other programming for optimising concrete mixes. Thejas et al. (2017) [3] discussed optimization of Mix design of self-compacting concrete using MATLAB. The different factors like Water Content, Volume of Paste, Water-cement ratio, Cement Content and Water-Powder content are taken as input parameters to produce output parameters include slump flow, L-box, U-box, J-ring, V-funnel and Compressive strength values at 7, 28, 60 and 90 days. The program developed in MATLAB is used in mix proportioning of SCC and has been validated with the experimental results. Manekya and Paul (2017) [4] developed a MATLAB program for design of High strength concrete mixes. Based on model developed by Erntroy and Shacklock (1954) [5], the program has been created. The data obtained from the method was transformed into suitable modal equations that are to be used in the MATLAB program. The program was then tested for various mixes and the program proved to be an alternative to the manual approach of design.

Owing to wide use and applicability of GAs, researchers attempted to carry out optimization problems of mix design using GAs and fuzzy techniques. Xie et al. (2011) [6] explained the design of high-performance concrete using optimization tool i.e., genetic algorithm toolbox. In this work, authors formulated a mathematical model where the performance of material was considered as constraint and the economic cost as an optimization target. Comparing the results obtained with practical engineering case, they concluded that GA could reduce cost, save energy and serves as a good engineering solution. Goldberg and Samtani (1986) [7] developed a genetic algorithm to determine the optimal weights of industrial buildings, with rectangular geometry projection and uniform planar structures (steel truss roofs) which are inter-connected by purlins. The planar structures are trusses. The number of trusses, shape and topology are the parameters in optimization technique. This method was proved to be successful, and the configuration can be directly used for construction.

Kwon et al. (2014) [8] developed a numerical technique to obtain optimum concrete mix proportions for reinforced concrete structures under carbonation. The fitness function for CO2 diffusion coefficient is derived from regression analysis and is implemented in Genetic Algorithms. This technique resulted in concrete mix proportions for structures apart from satisfying service life. Hamed (2019) [9] has investigated for the overall cost optimization of No- Slump Concrete (NSC.) Maintaining the strength of concrete as 65 MPa, he intended to obtain the cheapest concrete. Particle Swarm Optimization Algorithm (PSO) and GA were adopted to find the possible finest solutions. Compared to GA, PSO produced concrete mix which was 2% cheaper. Lim et al. (2004) [10] developed genetic algorithm to obtain the mix proportion of high-performance concrete, In this method 189 sets of concrete mixes were considered, out of which 181 sets were prepared using the Genetic Algorithm and the results obtained from these 181 sets were compared and validated with the remaining 8 sets. GA method was found to be time saving and accurate. Maruyama et al. (2003) [11] considered the mix proportioning problem as multi criteria optimization problem. Pareto optimality was employed for deriving the optimum solution and further applied it to a genetic algorithm.

Researchers also soon realised the significance of fuzzy techniques such as ANN for optimisation of concrete mixes and also for the prediction of strength characteristics. Duan et al. (2013) [12] have shown the suitability of artificial neural networks (ANNs) to forecast the compressive strength of recycled aggregates based concrete. The ANN model was trained and tested using 146 sets. The ANN model developed used 14 input parameters, these parameters included the properties and materials of concrete. The study concluded that this technique of ANN can be used to determine the compressive strength of various recycled aggregate concrete. Parichatprecha et al. (2009) [13] developed a mix optimization system for high-performance concrete (HPC) based on an integrated technique through ANN and GA. The three main properties of concrete- strength, durability and workability are predicted using ANN and these were used as constraints in GA. The fluctuating unit price of materials was also considered in this work. Authors concluded that the results obtained from this hybrid model can be used for the design of HPC mix meeting the required performance.

Abdelfeteh et. al(2016) [14] worked on a hybrid method which included machine learning algorithm to model the properties of HPC combined with Genetic Algorithms technique to optimize a particular specification of concrete(compressive strength and workability). It was concluded that the application of GP provided good results and proved to be advantageous. Li Yue et.al (2020) [15] studied the influence of concrete mix proportions on characteristics of concrete using ANN. Based on the results, Genetic Algorithms is used to mix proportion by improving the crack resistance. Authors concluded that the cracking risk coefficient was reduced by 25% by using this method.

Vidya Angadi et. al.(2016) [16] investigated on prognostication of Concrete Mix Proportion using Soft Computing Technique. This work is based on developing a structured equation (a process of developing coefficients) and Artificial Neural Network is adopted to obtain optimized mix proportions. Munot. et. al. (2014)[17] explored the compressive strength of Ready Mix Concrete (RMC) through the application of feed forward back propagation neural networks, Fuzzy Logic, and Adaptive Neuro Fuzzy Inference System (ANFIS) modelling.

In the recent years, many researchers have made use of various methods such as ANN, GA etc. to forecast the characteristics of concrete made by various mix proportions. This is primarily because of benefits of these approaches: (1) easy to use, as these methods have the capability to learn directly from samples, i.e. the relation between input and output parameters are produced by the data themselves. (2) More correctness, these methods can bear relatively incomplete tasks, approximate outcomes, and even less susceptible to outliers [18].

3. METHODOLOGY

3.1 Working of Genetic Algorithm

Optimization in GA involves various types of operations like creation, selection, crossover, mutation, etc. There are several options and methods for each operation.

The working of GA is as follows: The population size, maximum number of generations, GA parameters is given by the user in GA toolbox. The GA creates initial population. It evaluates fitness of each individual in the population. GA checks whether the termination criteria are met or not, if yes, GA finds for the best chromosome and gives as the result. If not, individuals in the population are selected as parents for next generation; crossover and mutation operations are performed on the individuals to produce new population. Again the same procedure is repeated till the termination criteria are met. The working of GA is shown in Figure 1.

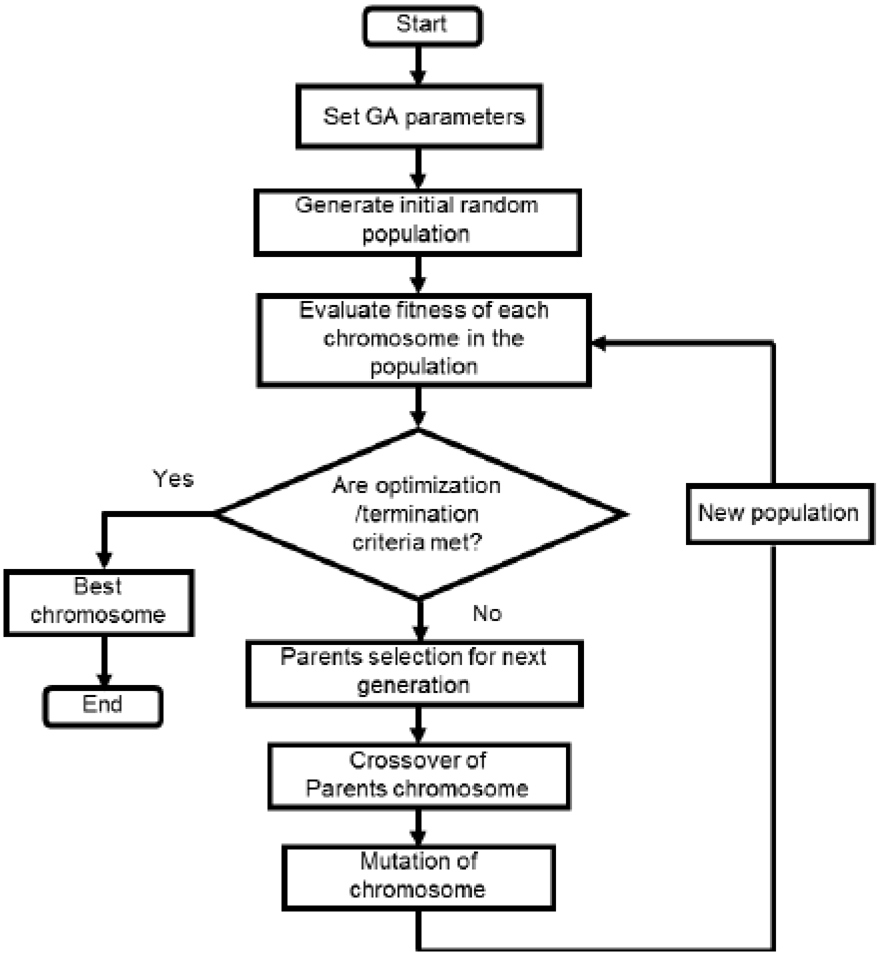

Figure 1. Flowchart showing GA procedure

3.2 Modelling the Function in GA

Fitness function is the function that is to be optimized. Water to cement ratio forms a major parameter in the concrete mix, as it defines the workability and strength of concrete. Abrams' water-cement law defining the relationship between compressive strength of concrete and water to cement ratio is used as fitness function. The function is given in separate folder and the address of the function (function name) is given in GA toolbox. The function given is as follows:

$$Y = - (a/(b^{(1.5*X)})) \tag{1}$$

Where

Y is the compressive strength of concrete
X is water to cement ratio
a, b are constants a=14000psi=96.52MPa, b=4
Constraints: Linear Inequality Constraints

In the case of concrete mix design it is given that hydration in concrete starts when w/c ratio is in the range of 0.22 to 0.25.

Assuming that, when w/c ratio=0.23, hydration starts, the linear inequality equation is given by

$$Ax+B<0 \tag{2}$$

Considering the above condition A=3.1 and B=0.23

This constraint ensures that the hydration process is adequately accounted for during optimization. By incorporating this fitness function and its constraints into the GA toolbox, the algorithm systematically optimizes the mix design to achieve a balance between material efficiency and structural performance. This approach results in an economical, high-strength concrete mix that meets both functional and durability requirements, making it a valuable tool for modern civil engineering applications.

3.3 Parameters Considered in Genetic Algorithm

There are many parameters and functions, which are involved in the performance of GA. The various parameters considered in the algorithm are shown in Figure 2

Parameter/Function name	Significance	Value used
Creation Function	function that is used to create population for the problem	Default value
Fitness function	fitness function is the function that is to be optimized.	name of the fitness function is given after the'@' symbol.
Number of variables	Number of variables	Water to cement ratio
Feasible Population	creates random initial population that satisfies all constraints and bounds	Not applicable
Fitness Scaling Options	convert the raw fitness values that are reverted by the fitness function to the values in the range which are suitable for the selection function	Default value
Selection Options	specify how the genetic algorithm chooses parents for the next generation	'Tournament Selection' function is used
Mutation Options	specify how genetic algorithm makes small random changes in the individuals in the population to create mutation children	Default tournament size of 4
Adaptive Feasible	generates random directions that are adaptive with respect to last successful or unsuccessful generation	Default value
Elite count	specifies the number of individuals that are guaranteed to survive to the next generation set	2.5
Crossover Options	states the fraction of next generation, other than the elite children, that are produced by crossover	0.8
Generations	States the maximum number of reiterations	100
Time limit	Specifies the maximum time in seconds that GA runs before stopping.	Default value
Fitness limit	algorithm stops if the best fitness value is less than or equal to the fitness limit	Default value
Stall generations	If the average relative change in the best fitness function value over Stall generations is less than or equal to Function tolerance, then the algorithm stops	Default value
Stall time limit	If there is no development in the best fitness value for an interval of time in seconds specified by Stall time limit, then the algorithm stops	Default value
Function tolerance	If the average relative change in the best fitness function value over Stall generations is less than or equal to Function tolerance, then the algorithm stops	Default value

Figure 2. Parameters or Functions considered in GA

3.4 Coding in MATLAB

Considering the concrete mix design procedure (BIS Method) and the Guidelines for Concrete Mix Proportioning IS 10262:2009 [19] a design code is formulated and executed in MATLAB. The design code is as follows:

For the given grade of concrete, target strength is calculated as follows:

$$ts = fck + 1.65*S \quad (2)$$

where

ts is the target strength of concrete
fck is the characteristicstrength of concrete
S is the standard deviation

Maximum water to cement ratio corresponding to the grade of concrete according to the guidelines IS 10262 [19] is shown below: -

The maximum water to cement ratio for M20 (Reinforced Concrete) is 0.55.
The maximum water to cement ratio for M25 (Reinforced Concrete) is 0.5.
The maximum water to cement ratio for M30 (Reinforced Concrete) is 0.45.

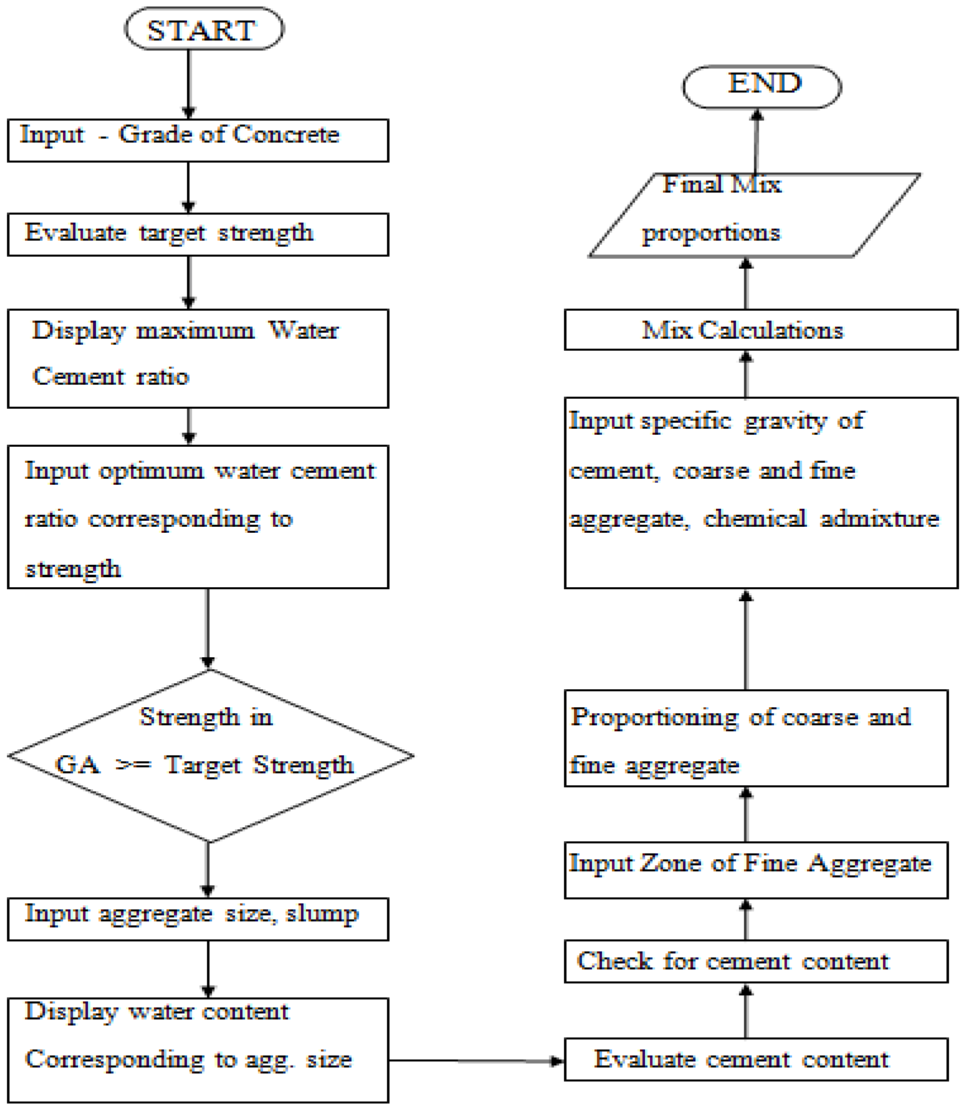

Figure 3. Flowchart showing GA procedure

Depending upon the maximum water to cement ratio a range of water to cement ratio is considered in Genetic Algorithm tool for optimization and optimum water to cement ratio and the corresponding strength obtained are given as inputs in the design code. The code compares the strength obtained in Genetic Algorithms to the target strength of concrete as obtained from equation 2. The strength obtained in Genetic Algorithms should be greater than or equal to the target strength of concrete. This condition is checked in the design code to maintain the strength of concrete. The code is based on mix design procedure involving the parameters of the materials as inputs from the users. The design code includes check for minimum cement content and maximum water to cement ratio. Considering the inputs, mix calculations are performed and final mix is obtained on executing the code. The design procedure adopted for mix design of concrete in MATLAB is demonstrated in Figure 3.

The program begins with giving the grade of concrete as input. The next step is to decide the standard deviation value depending upon the grade of concrete and then target strength is determined. All the inputs for the code are given in the command window step-by-step and the results are obtained in the command window itself. The variables are stored in the workspace and exported for further analysis.

4. RESULTS

The study results show relation between compressive strength and water-to-cement (w/c) ratio for concrete grade M20, M25, and M30. Concrete mix designs were done by varying the w/c ratio by 0.01, then compressive strength values (in MPa) were plotted for each grade. The plot shows a clear inverse tendency as compressive strength increases as w/c ratio decreases.This trend matches up with Abrams' water-cement law, which highlights the importance of the w/c ratio when it comes to the strength of concrete.

The maximum allowable wc ratio's of all non-blended and blended grades were found from Indian standards using the plotted data (Figures 5 and 6 respectively). This w/c ratio is limited to 0.55 for M20 concrete to meet specified strength and durability requirements. For M25 and M30 grades, the maximum w/c ratios are similarly limited to 0.50 and 0.45, respectively.This is due to the fact that the higher grade concrete generally has more strength and performance requirements that need that the amount of water for the amount of cement to be lower.

Thus emphasizing the importance of an optimum w/c ratio in mix designs to obtain the required compressive strength according to the standard guidelines. It shows how optimization techniques, such as the use of Genetic Algorithms, can be used to improve the overall process of mix design leading to higher quality concrete with optimal utilization of material. This method is especially suitable for precision-based applications and sustainable construction.

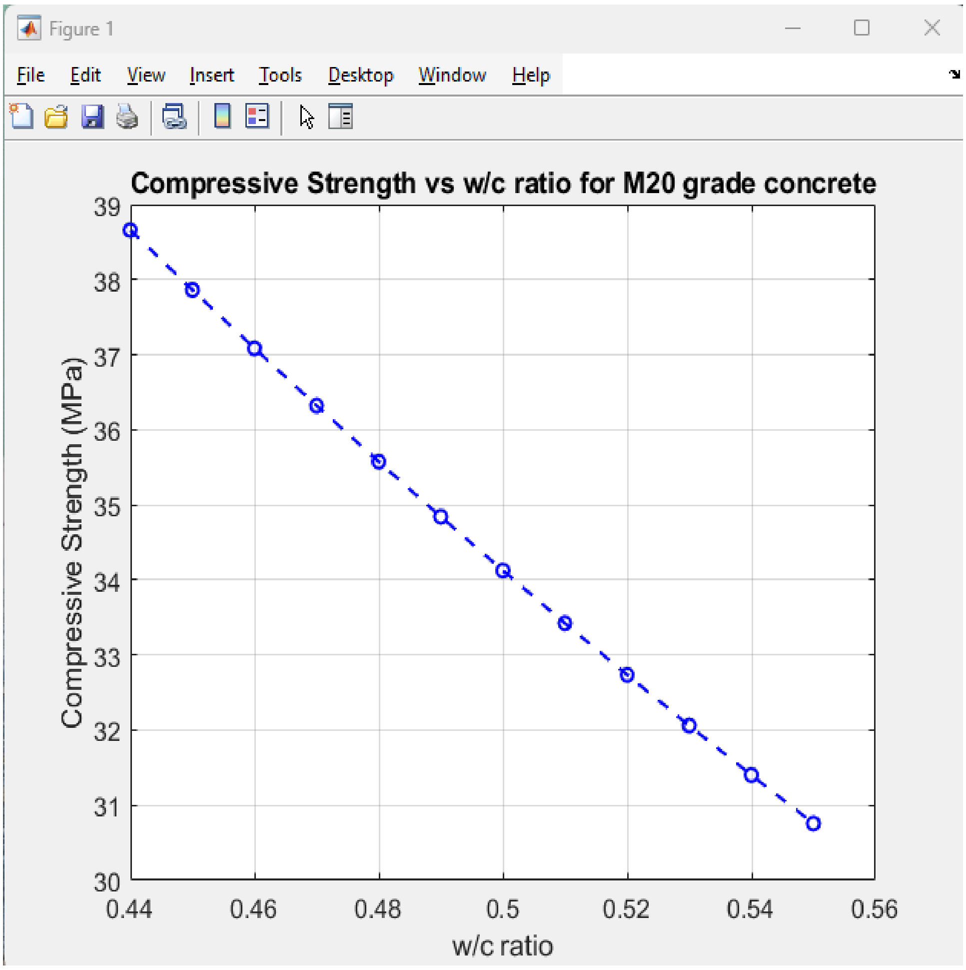

Figure 4. Compressive Strength vs w/c ratio for M20 grade concrete

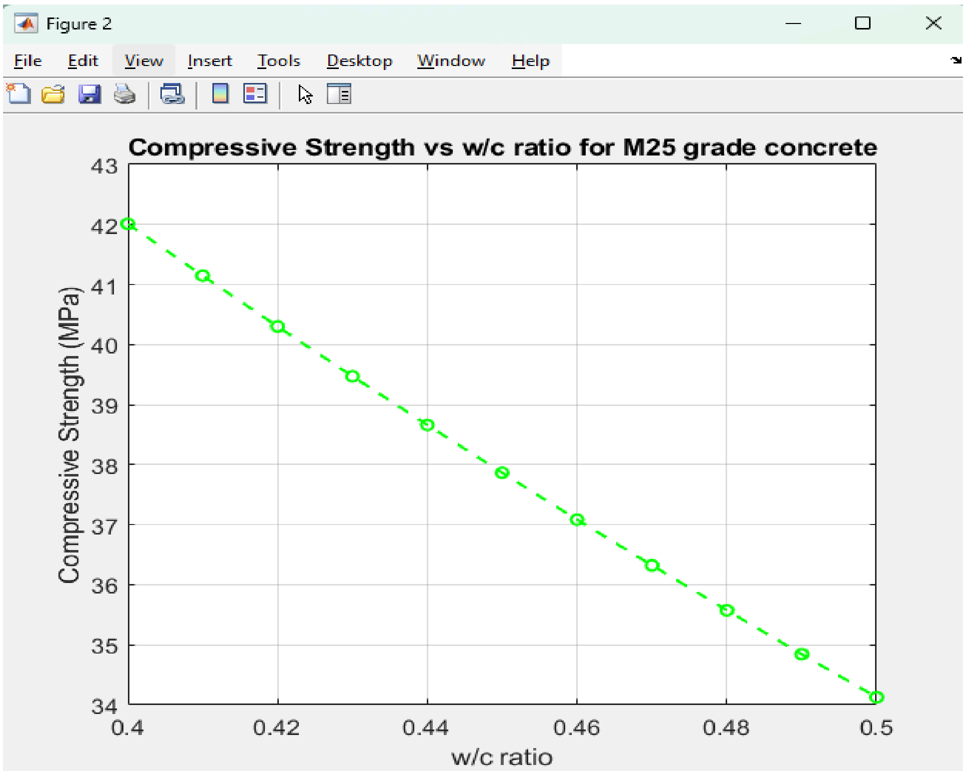

Figure 5. Variation of Compressive Strength with w/c ratio for M25 grade concrete

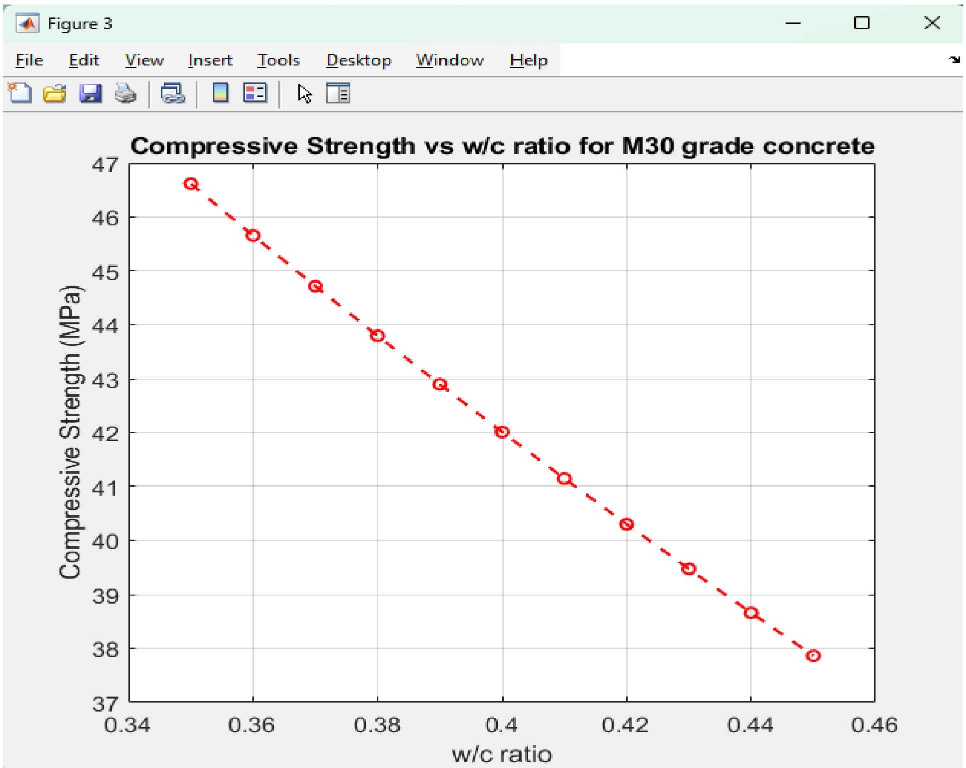

Figure 6. Compressive Strength vs w/c ratio for M30 grade concrete

The mix proportions obtained using GA optimization technique are compared to mixes obtained using manual approach as shown in Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6. It can be observed from tables that quantities of cement have been reduced by about 25-40 kg per cubic meter through mix design using GA technique.

Table 1. Comparison of mix obtained in GA with mix designed manually for M20 grade concrete with w/c ratio of 0.5

Item Details	Quantites obtained through Mix design using GA	Quantites obtained through Mix design due manually
Cement (kg/m3)	315.4	350
Water (kg/m3	157.72	175
Fine aggregate (kg/m3)	729.4	609.91
Coarse aggregate (kg/m3)	1217.6	1188.95
Chemical admixture (kg)	3.78	4.1
Workability	Medium	Medium
Strength (MPa)	34.125	33.5

Table 2. Comparison of mix obtained in GA with mix designed manually for M20 grade concrete with w/c ratio of 0.55

Item Details	Quantites obtained through Mix design using GA	Quantites obtained through Mix design due manually
Cement (kg/m3)	300	320
Water (kg/m3	157.72	176
Fine aggregate (kg/m3)	753.72	559.83
Coarse aggregate (kg/m3)	1206.1	1132.5
Chemical admixture (kg)	3.6	3.7
Workability	Medium	Medium
Strength (MPa)	30.75	28

Table 3. Comparison of mix obtained in GA with mix designed manually for M25 grade concrete with w/c ratio of 0.45

Item Details	Quantites obtained through Mix design using GA	Quantites obtained through Mix design due manually
Cement (kg/m3)	350.5	380
Water (kg/m3	157.72	171
Fine aggregate (kg/m3)	676.8	646
Coarse aggregate (kg/m3)	1215.5	1238.8
Chemical admixture (kg)	4.2	4.5
Workability	Medium	Medium
Strength (MPa)	38.25	33.4

Table 4. Comparison of mix obtained in GA with mix designed manually for M25 grade concrete with w/c ratio of 0.48

Item Details	Quantites obtained through Mix design using GA	Quantites obtained through Mix design due manually
Cement (kg/m3)	328.6	360
Water (kg/m3	157.72	172.5
Fine aggregate (kg/m3)	717.64	723.7
Coarse aggregate (kg/m3)	1218.47	723.7
Chemical admixture (kg)	2.4	2.5
Workability	Medium	Medium
Strength (MPa)	35.57	34.62

Table 5. Comparison of mix obtained in GA with mix designed manually for M30 grade concrete with w/c ratio of 0.41

Item Details	Quantites obtained through Mix design using GA	Quantites obtained through Mix design due manually
Cement (kg/m3)	384.7	420
Water (kg/m3	157.72	172.2
Fine aggregate (kg/m3)	671.9	649.3

Coarse aggregate (kg/m3)	1211.6	1238.4
Chemical admixture (kg)	4.6	4.5
Workability	Medium	Medium
Strength (MPa)	41.14	39.36

The cost of cement is very high when compared to the cost of other ingredients in concrete mix. In some cases, the quantities of water, coarse and fine aggregates have slightly increased. However, it is a less marginal increase since the cost of these materials are significantly less when compared to that of cement. Also, the availability/scarcity of the cement is one of the key factors in mix design of concrete. Thus, cost of cement is largely affected by the quantities and cost of cement. Concrete mix design done using Genetic Algorithms (MATLAB) has shown significant decrease in the cement quantities measured in kg/cum. Figure 6 shows the variations in quantities of cements for various mix designs through manual design and GA design. It can be clearly seen that quantities of cement are significantly reduced for all the cases of mix design using GA optimization approach.

Table 6. Comparison of mix obtained in GA with mix designed manually for M30 grade concrete with w/c ratio of 0.42

Item Details	Quantites obtained through Mix design using GA	Quantites obtained through Mix design due manually
Cement (kg/m3)	375.5	400
Water (kg/m3	157.72	168
Fine aggregate (kg/m3)	678.55	644
Coarse aggregate (kg/m3)	1213	1232
Chemical admixture (kg)	4.5	4.8
Workability	Medium	Medium
Strength (MPa)	40.3	40.2

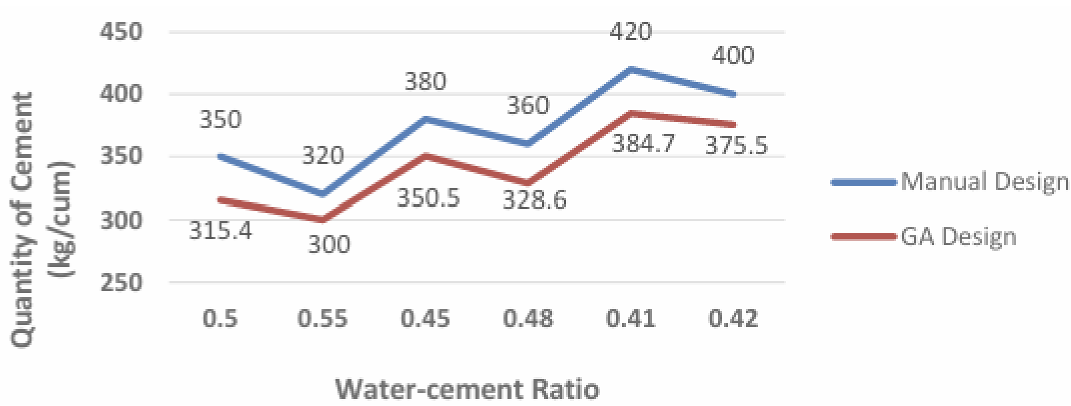

Figure 7. Quantity of Cement for various mix design cases

The percentage decrease in the cement quantities for different grades of concrete with various water- cement ratios is displayed in Table 7. It can be seen that cement quantities are reduced by about 6-10% for various cases of grades and water cement ratio.

Table 7. Percentage reduction in cement quantities using GA technique in comparison to manual method

Grade of Concrete	W/C Ratio	Percentage reduction in cement quality using GA
M20	05	9.9
	0.55	6.3
M25	0.45	7.8
	0.48	8.7
M30	0.41	8.4
	0.42	6.1

5. CONCLUSIONS

The work has been implemented using highly computational software – MATLAB (The Language of Technical Computing). But the implementation of MATLAB program makes the design procedure efficient. Mix design performed using optimization techniques like GA proved to be efficient when compared to mix design using manual approach. The computation time using the program is less hence can be effectively used. The design of concrete mix using a developed MATLAB program and implementing Genetic Algorithm to it showed better optimization results when compared to manual approach. The optimized mix proportions obtained from this technique can be used to prepare a concrete mix with high strength. This work can be further extended to determine the concrete properties like durability, workability, etc. for the mix proportions obtained using this technique. The present study highlights the concrete mix design procedure using GA approach for obtaining economic mix proportions in less time and highly efficient manner. The study can be further extended for evaluating the optimum contents of admixtures used for cement or concrete mixes. This program can be further modified depending upon the requirements for different types of concrete. The program can be extended to different tests for concrete like self-compacting concrete. The Genetic Algorithm fitness function can be replaced by any other function depending upon the criteria to optimize, having the same MATLAB program. Further, the models for predicting compressive strength under different proportions of materials can also be analyzed using GA approach presented in this study.

6. REFERENCES

[1] Murthy, D.Zealakshmi & Ravichandran, A. & Kothandaraman, S.. (2013). Computer Aided High Strength Concrete Mixture Proportion using Mat Lab. International Journal of Computer Applications. 70. 18-25. 10.5120/11982-7857.

[2] W.Park. Genetic Algorithm based mix proportion design method for Recycled Aggregate Concrete,Trans. Can. Soc. Mech,Eng., vol 37, no. 3, pp.345-354,2013.

[3] M, Thejas & J, Manjunath & L, Shruthi. (2017). Optimization of mix design of self-compacting concrete using matlab. International Journal of Research in Engineering and Technology. 06. 20-26. 10.15623/ijret.2017.0617004.

[4] Makenya A. R., John Paul M., Potentiality of Using a Developed MatLab Program for the Design of High Strength Concrete Mixes, Journal of Civil Engineering Research, Vol. 7 No. 3, 2017, pp. 81-98. doi: 10.5923/j.jce.20170703.01.

[5] Erntroy, H. C. and Shacklock, B. W., 1954. Design of High-strength Concrete Mixes. s.l.:Cement and Concrete Association.

[6] Xie, Xian & Yan, Dong & Zheng, Yue. (2011). Optimization Design Of High-Performance Concrete Based On Genetic Algorithm Toolbox Of Matlab. Advanced Materials Research. 250-253. 2672-2677. 10.4028/www.scientific.net/AMR.250-253.2672.

[7] Goldberg, D.E., & Samtani, M.P. (1986). ENGINEERING OPTIMIZATION VIA GENETIC ALGORITHM, IN WILL.

[8] Kwon, Seung-Jun & Lee, Byung-Jae & Kim, Yun. (2014). Concrete Mix Design for Service Life of RC Structures under Carbonation Using Genetic Algorithm. Advances in Materials Science and Engineering. 2014. 1-13. 10.1155/2014/653753.

[9] Naseri, Hamed. (2019). Cost Optimization of No-Slump Concrete Using Genetic Algorithm and Particle Swarm Optimization. International Journal of Innovation, Management and Technology. 10. 10.18178/ijimt.2019.10.1.832. concrete.

[10] Lim, C. H., Yoon, Y. S., & Kim, J. H. (2004). Genetic algorithm in mix proportioning of high performance Cement and https://doi.org/10.1016/j.cemconres.2003.08.018

[11] Maruyama, I., Noguchi, T., & Kanematsu, M. (2002). Optimisation of the concrete mix proportions centred on fresh properties using genetic algorithm. Indian Concrete Journal, 76(9 SPEC), 567-573.

[12] Duan, Z.H., Kou, S.C., and Poon, C.S. (2013), "Prediction of compressive strength of recycled aggregate concrete using artificial neural networks". Construction andBuilding Materials, Vol. 40, pp.1200-1206.

[13] Parichatprecha, Rattapoohm & Nimityongskul, Pichai. (2009). An integrated approach for optimum design of HPC mix proportion using genetic algorithm and artificial neural networks. Computers and Concrete. 6. 10.12989/cac.2009.6.3.253.

[14] Sadok, Abdelfeteh & Zentar, Rachid & Abriak, Nor-Edine. (2016). Design of high-performance concrete mixture based on alternative materials using the hybrid method of genetic algorithm and genetic programming.

[15] Yue L, Hongwen L, Yinuo L and Caiyun J (2020). Optimum Design of High-Strength

Concrete Mix Proportion for Crack Resistance Using Artificial Neural Networks and Genetic Algorithm. Front. Mater. 7:590661. doi: 10.3389/fmats.2020.590661

[16] Angadi, Vidya & B S, Keerthi Gowda & Easwara, Prasad & Ramachandran, Velmurugan. (2016). Prognostication of Concrete Mix Proportion using Soft Computing Technique.

[17] Mr. Vipin V. Munot (2014). Compressive Strength of Ready Mix Concrete Using Soft Computing Techniques. Int. Journal of Engineering Research and Applications. ISSN : 2248-9622, Vol. 4, Issue 12(Part 3), December 2014, pp.12-14

[18] B. Topçu, M. Sarıdemir. Prediction of properties of waste AAC aggregate concrete using artificial neural network Comput Mater Sci, 41 (1) (2007), pp. 117–125.

[19] Code of Practice for Concrete mix Proportioning-guidelines, IS10262 (2009), Published by Bureau of Indian Standards.