iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IV **Month of publication:** April 2021

DOI: https://doi.org/10.22214/ijraset.2021.33465

Material Modeling of Wheat Straw Reinforced Concrete for Pavement Application

Muhammad Faheem[1], Dr. Awais Ahmad[2], Dr. Ravid Khan[3]
[1]Engr, [2]Assistant Professor, [3]Professor, Civil Engineering Department, University of Science and Technology, Peshawar

Abstract: In this research analytical and numerical models of already experimented compressively tested Plain and wheat straw reinforced concrete (WSRC) cylinders have been developed for pavement application. The experimental data consist of plain concrete (PC) and wheat straw reinforced concrete with 1%, 2%, and 3% wheat straw fiber by weight of wet concrete. Analytical expression based on experimental results developed by taking Carreira and Chu, 1985 [1] as a reference and parameters of it has been developed by curve fitting technique in Matlab. The result of an analytical expression is then modeled in ABAQUS which is finite element software and checks the behavior of concrete cylinder by concrete damage plasticity model (CDPM). Developed analytical expression results in resonance with that of experimental results of plain concrete and that of WSRC. Similarly, the stress-strain curve resulted from CDPM perfectly matches with the analytical stress-strain curve.
Keywords: Abaqus, Concrete Damage Plasticity Model, Rigid Pavement, Wheat Straw Reinforced Concrete.

I. INTRODUCTION

Fiber-reinforced is composite material on macroscopic level consist Reinforcement **(**this phase is discontinuous, stronger and stiffer) and Matrix (This phase is continuous, weaker, and less stiff) phase [2]. Mechanical property and its performance of these two phases superimpose when they act together in comparison if these act independently. Rigid pavement material generally consists of concrete either plain or reinforced with steel or any artificial fiber. Failure of the rigid pavement due to early-age cracking is a normal trend. From research, it has been proved that use of natural fiber as reinforcement in concrete control plastic and drying shrinkage, reduce bleeding by reducing the permeability of concrete and enhance the ductility of concrete by increasing tensile strength because excess energy is dissipated by the addition of fiber [3]. Different fibers are used to decrease early-age cracking. Sinha, (2014) [4] added discretized steel fibers at the rate of 0.5%, 0.75%, 1.0%, 1.25%, 1.50%, 1.75%, and 2.0% by volume fraction to plain concrete to reduce plastic and drying shrink cracking are reduced by using discretized steel fibers as reinforcement in plain concrete. With the addition of steel fibers up to 1% increase the compressive strength and other parameter but with onward proportion compressive strength decrease, hence from an economic point of view 1%, SFRC is better. Similarly, Kiachehr Behfarnia and Niloofar Salemi, 2013 [5] added Nano alumina and Nano silica to plain concrete mix @ 5% and 3% by weight of concrete respectively along with admixture for frost resistance and mechanical properties for rigid pavement. Frost resistance and compressive strength of NSRC improved by 83% and 30% respectively and that of NARC 81% and 8%. Strength property of concrete reinforced with wheat straw (natural fiber) @ 1%, 2%, and 3% by volume fraction was experimentally analyzed for rigid pavement application which results in an increase in compressive energy and toughness index by 162% and 91% respectively in comparison to PC [6] also decrease the formation of early-age cracking due to its mechanical property.

Wheat straw reinforced concrete is new material in transportation engineering and it is not as much studied which is to be. Hence experimental compression test was conducted by [6] but there is no such analytical expression and no numerical model through which to simulate the result. Numerical modeling is similar to that of the experimental test as it provides the same environment as that of the lab. The positive aspect of numerical modeling is that you can analyze each point of the model specimen.

Concrete is a complex material and the property can't be studied at the micro-level through lab tests hence to examine it must be simulated through FEA simulation software. In this research, an effort has been made to develop an analytical model for the experimentally tested cylinder for plain concrete and wheat straw reinforced concrete (for different weight fiber ratio). Then it is validated by a numerical model based on the concrete damage plasticity model (CDPM) in 3D simulated software ABAQUS.

II. ANALYTICAL MODELLING OF FIBER REINFORCED CONCRETE

Different researchers experimentally studied behavior fiber reinforced concrete for different purposes and present stress-strain data either in form of tables or graphs. One step further from this presentation is analytically in which all parameters are combined in general mathematical form in such a way that its result is similar to that of the experimental result. Many researchers develop such expression for stress-strain data of plain and that of fiber reinforced concrete some of which follow as

Carreira and Chu, 1985 [1] developed an expression for concrete bases on the experimental compressive test that represents a complete stress-strain relationship in compression

$$\frac{F_c}{f'_c} = \frac{\beta\left(\frac{\epsilon}{\epsilon'_c}\right)}{\beta-1+\left(\frac{\epsilon}{\epsilon'_c}\right)^{\beta}} \quad where \;\; \beta = \frac{1}{1-\frac{f'_c}{\epsilon'_c E_{it}}}$$

β is a material property that depends on the shape of the stress-strain diagram. The parameter f'_c, ϵ'_c, β and E_{it} can be determined from displacement rate controlled compression test. The above expression results in a curve from developed expression well fitted with the experimental stress-strain curve hence accurately defined the compressive behavior of concrete.

A similar effort was made by M.C. Nataraja, (1999) [7] to use a similar approach to that of [1] for steel fiber reinforced concrete but define a parameter of expression in terms of steel fiber reinforcing index. The parameter based on RI is given as

$$f'_{cf} = f_c + 2.1604(RI);\;\; \varepsilon_{of} = \varepsilon_o + 0.0006RI;\;\; E_i = 1930RI^{(-0.7406)};\;\; \beta = 0.5811 + 1.93RI^{(-0.7406)}$$

From fig.1 it is cleared that the stress-strain curve generated from analytical expression in parallel with an experimental curve, hence the developed expression accurately defined the compressive behavior of SFRC.

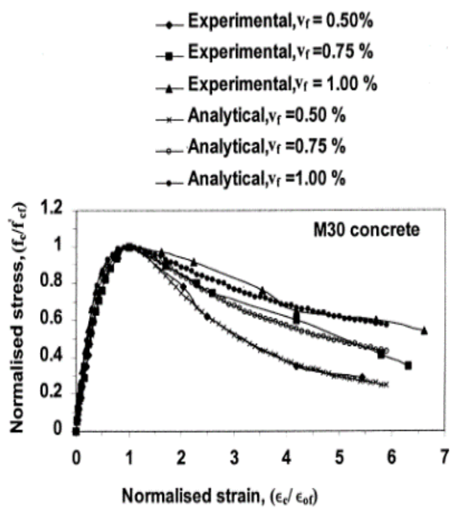


Figure 1: Normalized Stress Strain Graph of M30 Concrete of Various Fiber Volume Ratio [6]

Mansur, 1996 [8] developed an analytical expression for defining the compressive stress-strain relationship of high strength based on experimental tested of 163 cylindrical specimens (100 X 200 mm) with compressive strength ranging from 50 MPa to 120MPa.

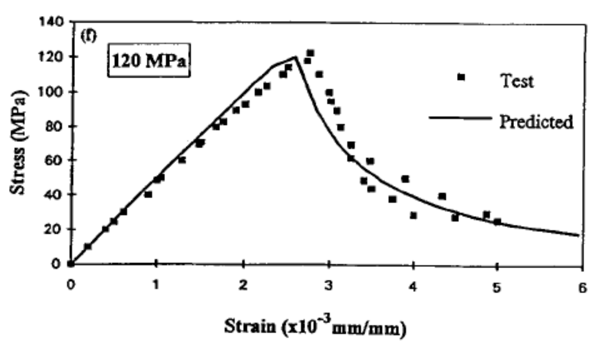


Figure **Error! No text of specified style in document.**: Comparison Stress Strain Graph of Experimental and Predicted Equation [7]

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

Seong Cheol Lee, Joung Hwan Oh, and Jae Yeol Cho, 2015 [9] experimentally investigate compressive behavior of SFRC by uniaxial testing 48 cylinder and developed the analytical expression by taking Carrira and Chu [1] equation taken as a reference and define it for both pre and post-peak compression behavior. Analytical expression parameter was defined in terms of fiber volumetric and aspect ratio.

The modified analytical expression is as follow,

$$\frac{f_c}{f'_c} = \frac{A\left(\frac{\varepsilon_c}{\varepsilon_{of}}\right)}{A - 1 + \left(\frac{\varepsilon_c}{\varepsilon_{of}}\right)^B}$$

Whereas equation for parameter developed through regression analysis is

$$\varepsilon_{of} = \left(\frac{0.0003V_f\, l_f}{d_f} + 0.0018\right) f_c'^{\,0.12} = (0.0003RI + 0.0018) f_c'^{\,0.12}$$

$$E_c = \left(-367V_f\frac{l_f}{d_f} + 5520\right) f_c'^{\,0.41}$$

Where parameters A and B reflect different effects for post and pre-peak behavior.

For pre-peak compressive behavior

$$A = B = \frac{1}{1 - \left(\frac{f'_c}{\varepsilon_o E_c}\right)} \qquad for\frac{\varepsilon_c}{\varepsilon_o} > 1.0$$

For post-peak compressive behavior

$$A = 1 + 0.723\left(\frac{V_f\, l_f}{d_f}\right)^{-0.957} \qquad for\frac{\varepsilon_c}{\varepsilon_0} > 1.0$$

$$B = \left(\frac{f'_c}{50}\right)^{0.064}\left[1 + 0.882\left(\frac{V_f\, l_f}{d_f}\right)^{-0.882}\right] \geq A\ in\ Equation\ (3)\ \ for\frac{\varepsilon_c}{\varepsilon_0} > 1.0$$

Similar to the above stress-strain data of plain concrete and reinforced concrete with wheat straw fiber from 1 to 3% by mass of wet concrete were collected from experimental results [6] as shown in fig. 1 with the help of plot digitizer. Carrira and chu [1] equation was taken as reference and the parameter was validated with the experimental data with the help of curve fitting technique in Matlab.

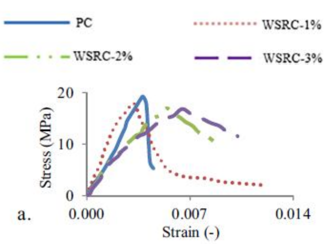


Figure 3: Experimental Compressive Stress Strain Curve of PC and WSRC

$$\frac{f_c}{f_{of}} = \frac{\beta * \left(\frac{\varepsilon_c}{\varepsilon_{of}}\right)}{\beta - 1 + \left(\frac{\varepsilon_c}{\varepsilon_{of}}\right)^{\beta}}$$

Where

f_c = Compressive Stress in (Mpa)

f_{of} = Compressive strength in (Mpa)

ε_c = Compressive Strain

ε_{of} = Compressive Strain at Peak Stress

β = Material Parameter

Stress-Strain graphs obtained from analytical expression were compared with experimental as shown in Fig.7. The graphical comparison shows that both ascending and descending branches of both curves well overlap with each other except that of 1%. As the strain at maximum stress computed through analytical equation follow the ascending linear relationship while in that of experimental strain at maximum stress first decrease in 1% WSRC and then it increases. As strain at maximum stress increase with the addition of fiber but in case of WSRC 1% it decreases and this is due to experimental inaccuracy and due to this, the two curve deviate from each other. Also, the peak strength of PC is greater than that of WSRC. Ascending portion of plain concrete is steep than that of WSRC, the drop-down of the descending portion of PC in comparison with WSRC is abrupt while WSRC is expended because due to the presence of fiber it doesn't break in brittle nature but show some ductility.
In WSRC 1% the descending branch shows more energy absorption than that of 2 & 3%.

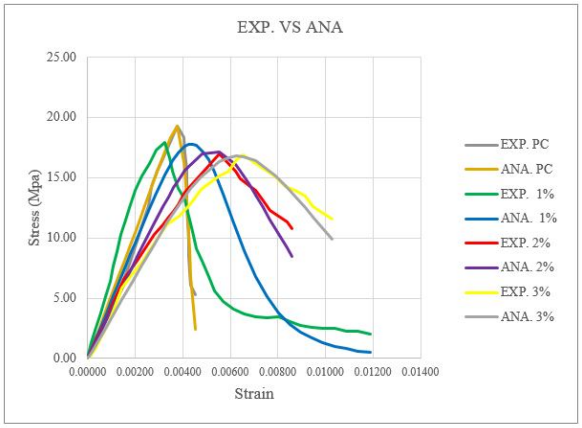


Figure 7: Comparison of Experimental Result with Analytical Model of PC and WSRC

III. NUMERICAL MODELING

Materials models and simulation tools are necessary to eliminate trial-and-error loops during the development of materials, components, and manufacturing processes, to illustrate complex load scenarios, and to make reliable predictions of the behavior of existing materials and components as well as for those in the process of development. A material model is an equation that relates the applied force (or stress) to the resulting deformation (or strain).
A variety of methods have been used to predict the properties of composite materials (concrete) [2]. Elasticity model, the discrete crack, the smeared crack model, the fictitious crack (FC) model, the Plasticity model, the Damage model, CDPM.
The effect of the addition of fiber on concrete can't be fully analyzed by an experimental procedure, as its deep behavior can be checked by stress analysis of each element of a structure. FEM is a numerical technique used for solving a problem related to engineering and mathematical model. Actually, in this method, the whole model or domain is subdivided or discretized into a smaller part called an element through the meshing technique. The behavior of each element is predicted by Mathematical equations. Similar to this approach Zuzana Marcalikova (2020) [10] simulated compressive strength, splitting tensile strength, and bending tensile strength from the three-point test data of fiber (Dramix OL 13/20 and Dramix 3D 65/60 BG) reinforced concrete in ATENA software for numerical modeling.
Following table show experimental results of both FRC

Table **Error! No text of specified style in document.**: Mechanical Property of FRC [10]

Mechanical properties	Type fibers	
	Dramix® 3D 65/60 BG	Dramix® OL13/20
Compressive strength – cubic $f_{c,cube}$ [MPa]	28.17	40.19
Splitting tensile strength – perpendicularly to the filling direction $f_{ct,sp,\perp}$ [MPa]	3.64	3.08
Three-point bend test $f_{ct,fl,3B}$ [MPa]	5.02	4.98

By using the mechanical property of concrete and fiber reinforced concrete resulted in an experimental test of a 3D model developed in ATENA, load-displacement (LD) curve was obtained as a resultant similar to the experimental LD curve.

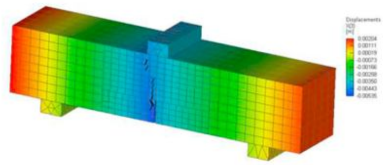
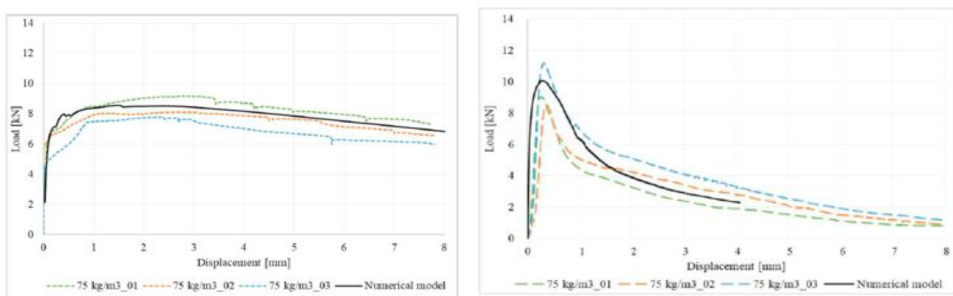


Figure 8: Computer Model with Crack. Fiber Dramix [10]



(a) (b)

Figure 9: Load Displacement Diagram for (a) Dramix 3D (b) Dramix OL [10]

Abaqus is FEA-based software used for the simulation of material used for material modeling.

Reza Nassir Zadeh Goorchi, 2015 [11] developed a concrete damaged plasticity model is for reinforced concrete beams in ABAQUS. There are certain parameter required for CDPM to describe the actual behavior of concrete are

Yield surface of concrete and flow potential

Degradation of elastic stiffness and the stress-strain relationship of concrete.

For the first parameter, the default value has been used shown in table 3, while for 2nd data taken from series of uniaxial compression and tension test.

Table 3: Typical range values for concrete damage plasticity parameters

Parameter	Parameter value
$\frac{\sigma_{b0}}{\sigma_{c0}}$	$1.10 < X < 1.16$
α	$0.08 < X < 0.1212$
β	$7.7 < X < 8.1$
K_c	$0.5 < X < 0.8$
$\in(\theta, f_i)$	0.1

The implicit procedure used for numerical modeling of RB in Abaqus. After analysis beam crack pattern appeared as shown in fig.8. Red lines show reinforcement bars that are embedded in finite element mesh. The crack pattern show similarity in its intensity and location to that in a lab test.

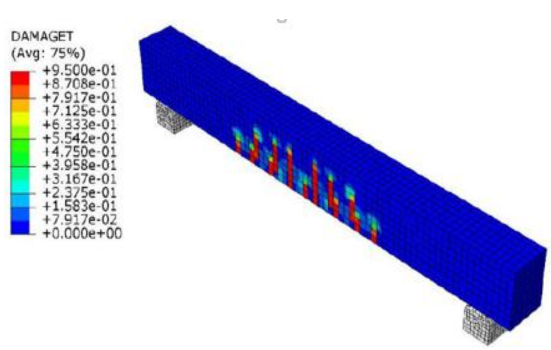


Figure 10: Reinforce Concrete Beam Crack Pattern [11]

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

Similar to [11] for material modeling of plain and wheat straw reinforced concrete cylinder CDPM was developed in, Abaqus/CAE or "Complete Abaqus Environment" [12]. Total four models were generated one that of PC and three of WSRC i.e. 1 to 3% of wheat straw fiber. The depth is defined as 200mm and diameter as 100mm while modeling space as 3D. As concrete exhibits nonlinear mechanical behavior due to the Plasticity and Damage Mechanism hence damage and plasticity model is defined for it [13], [14]. Tensile cracking and compressive crushing are the two main failure mechanisms of CDPM. The compressive behavior of concrete cylinder fig.2 was defined after peak stress and strain correspondingly in term of inelastic strain and compression damage was also defined in term of compressive stress σ_c and strength σ_{co}.

$$d_c = 1 - \frac{\sigma_c}{\sigma_{co}}$$

In uniaxial compression up to initial yield σ_{c0} the response is linear. Beyond the ultimate stress, σ_{cu} stress hardening is followed by strain-softening in the plastic concrete region. Stress-strain data concrete cylinder to be defined after the elastic range (σc0) and as a function of inelastic strain (εc.in) which is total strain minus the elastic strain corresponding to the undamaged material

$$\varepsilon_c^{.in} = \varepsilon_c - \varepsilon^{el}_{0c}$$

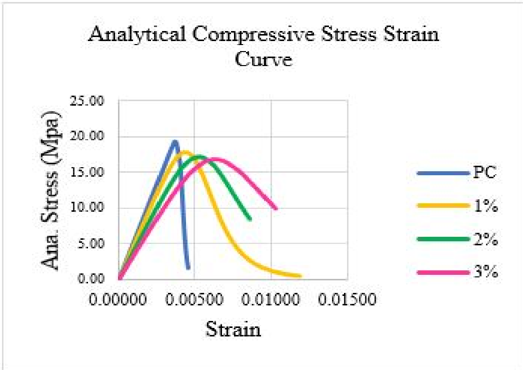


Figure 11: Graphical Comparison of Analytical Compressive Stress. Strain Curve PC and WSRC

Similar to compressive behavior tensile behavior was defined from fig. 12 in terms of cracking strain and tension damage. Under uniaxial tension, the stress-strain up to failure stress follows a linear elastic relationship. At σt0 micro-crack appears on the surface while beyond σt0 these micro-cracks are growing up and form a shape of macroscopic cracks with a softening stress-strain response.

$$\varepsilon_t^{.ck} = \varepsilon_t - \varepsilon^{el}_{0t}$$

Tension Damage describes post cracking damage properties for the CDPM also to specify compressive stiffness degradation damage. The model behaves plastically if uniaxial tensile damage is not specified.

$$d_t = 1 - \frac{\sigma_t}{\sigma_{to}}$$

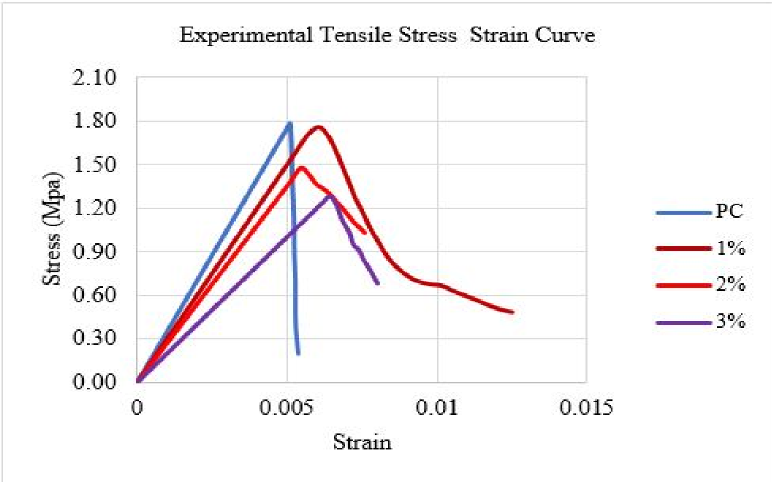


Figure 12: Typical Tensile stress strain graph of PC and WSRC

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

CDPM parameters include Dilation angle (ψ), Flow potential eccentricity (ϵ), fb0/fc0, Kc, Viscosity parameter (μ). The above parameter value based on the literature review has been put in a plasticity window as shown in fig 13.

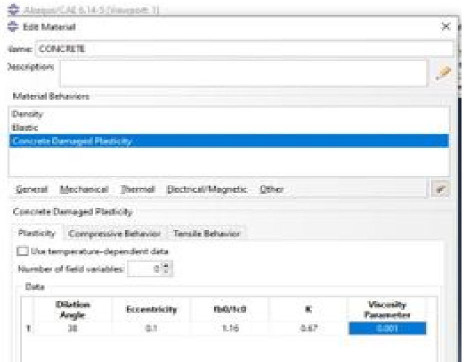


Figure 13: CDP Parameter of Plain Concrete

For load application reference point was created at top surface and constraint was defined as kinematic coupling constraint which restricts concentrated force (CF) and not coupled with other surfaces or nodes.

The load application procedure has been selected as static because the experimental setup was also static and step time has been defined as 1.0 sec, and load type was specified as displacement control as in this type mandatory load is measured and the rate of travel (displacement) is kept constant during the test. Displacement of u3 = -2 has been applied which is opposite of z-direction as cylinder lied in y-z axis as shown in fig. 14, hence along u3 = -2 has been specified for reference point. The boundary condition at the bottom surface was defined as fixed-point hence u1, u2, and u3 are specified as zero (0), while Top surface u1 and u2 are specified as zero (0) because there is no movement along with these two directions while u3 is already specified as -2 for a reference point which lied on the top surface. The concrete cylinder was divided into smaller elements called meshing by specifying approximate global size as 8.

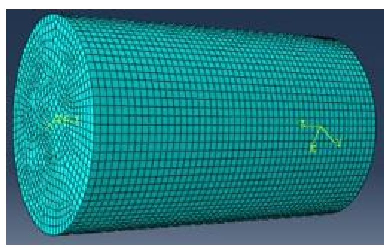


Figure 14: Meshed Concrete Cylinder

After running each model for analysis result in the following stress contour and stress-strain curve as shown in fig. 15 and 16 respectively. It shows that PC has high compressive strength in comparison to WSRC, as in experimental result also the compressive strength drop due to addition of fiber but increase in ductility as after peak point compressive strength of PC immediately drops vertically while that of WSRC line of graph extends from peak point show the absorption of energy by the fiber in conjunction with concrete. From fig. 12 and 13 stress-strain curve of experimental and analytical runs in parallel with that FEM result. Hence except WSRC-1% little bit deviate in an elastic portion which is explained in the analytical section and remaining superimpose each other. Hence FEM model expresses the analytical and experimental result in a very good manner.

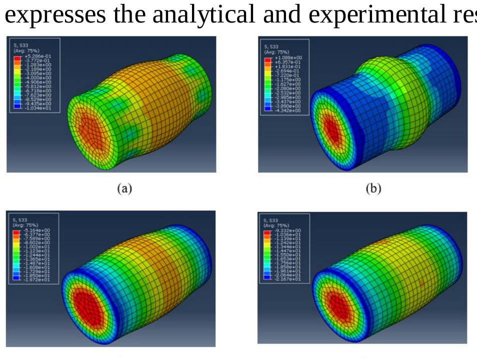


Figure 15: S33 Stress Contour at 2mm displacement and end step time (a) PC (b) WSRC-1% (c) WSRC-2% (c) WSRC-3%

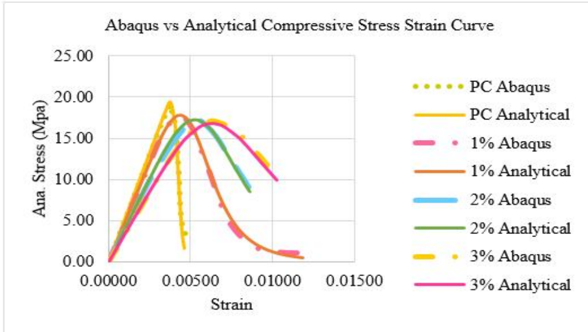


Figure 16: Comparison of Abaqus Result with Analytical Model of PC and WSRC

IV. CONCLUSION

The main theme of this research is to develop an analytical and numerical model for experimentally tested wheat straw reinforced concrete. An approach to model concrete reinforced with wheat straw fibers has been assessed by various parameter studies and comparisons to analytical results. Analytical expression was generated from modification of Carrirea and Chu equation [1] and its parameter equation was developed through Curve fitting technique in Matlab. The CDPM was generated through Abaqus/ CEA based on analytical computed data.

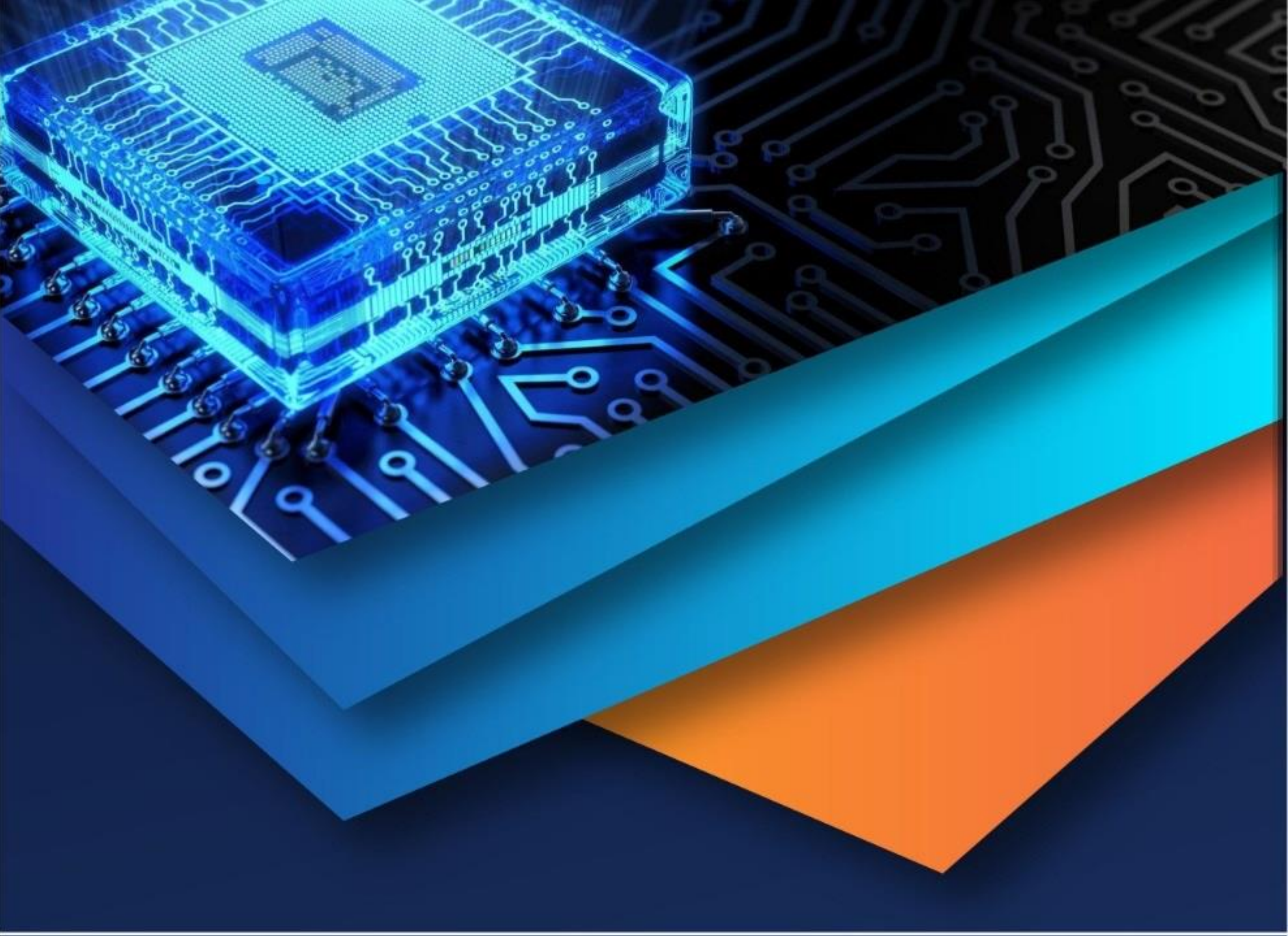
An analytical expression generated based on experimental result clearly express the experimental compressive stress-strain data as clear from the graph comparison of both curves. Also, the parameter of analytical expression well defines that in the experimental result. Both finite element and analytical stress-strain curves ascending and descending part overlap each other as shown in fig. 16. It means that CDPM accurately represents the experimental result. CDPM result based on 8 mesh size and variable viscosity parameter. By changing, mesh size results remain the same while changing viscosity parameter effect the output result.

V. ACKNOWLEDGMENT

First of all, I am thankful to Almighty ALLAH for supporting me in such an achievement within specified resources and time. Further, I am so grateful to Asstt. Prof Dr. Awais Ahmed and Tariq Mehmood (CEO of Earnest Pakistan Pvt. Ltd.) for their quality guidance and support.

REFERENCES

[1] K. H. Chu and D. J. Carreira, “Stress-strain relationship for plain concrete in compression,” ACI Mater. J., vol. 27, no. 8, pp. 797–804, 1985.
[2] I. M.Daniel and O. Ishai, Engineering mechanics of composite materials, 2nd Editio., vol. 1, no. 2. Oxford University Press, Inc., 1996.
[3] B. Some and S. See, “Fiber-reinforced concrete,” no. l, pp. 3–6.
[4] R. V Solanki, C. . Mishra, and S. Deepa, “Comparison of Normal Concrete Pavement with Steel Fiber Reinforced Concrete Pavement,” vol. 15, no. August, pp. 233–235, 2014.
[5] N. Salemi and K. Behfarnia, “Effect of nano-particles on durability of fiber-reinforced concrete pavement,” Constr. Build. Mater., vol. 48, pp. 934–941, 2013, doi: 10.1016/j.conbuildmat.2013.07.037.
[6] M. U. Farooqi and M. Ali, “Effect of pre-treatment and content of wheat straw on energy absorption capability of concrete,” Constr. Build. Mater., vol. 224, pp. 572–583, 2019, doi: 10.1016/j.conbuildmat.2019.07.086.
[7] M. C. Nataraja, A. . Gupta, and N. Dhang, “Stress ± strain curves for steel- ® ber reinforced concrete under compression,” vol. 21, no. 1999, pp. 1–8, 1999.
[8] L. Á. De Oliveira Júnior et al., “Stress-strain curves for steel fiberreinforced concrete in compression,” 65th ABM Int. Congr. 18th IFHTSE Congr. 1st TMS/ABM Int. Mater. Congr. 2010, vol. 7, pp. 5447–5454, 2010, doi: 10.1590/s1517-70762010000200025.
[9] S. C. Lee, J. H. Oh, and J. Y. Cho, “Compressive behavior of fiber-reinforced concrete with end-hooked steel fibers,” Materials (Basel)., vol. 8, no. 4, pp. 1442–1458, 2015, doi: 10.3390/ma8041442.
[10] Z. Marcalikova, D. Bujdos, and R. Cajka, “Approach to numerical modelling of fiber reinforced concrete,” Procedia Struct. Integr., vol. 25, no. 2019, pp. 27–32, 2020, doi: 10.1016/j.prostr.2020.04.006.
[11] R. N. Goorchi, M. Mohtadinia, and A. Jafari, “Numerical modeling of reinforced concrete structures with concrete damage plasticity,” 10th Int. Congr. Civ. Eng., no. January, pp. 1–8, 2015.
[12] ABAQUS, “ABAQUS Theory Manual,” ABAQUS Doc., p. 1176, 2010.
[13] U. Cicekli, G. Z. Voyiadjis, and R. K. Abu Al-Rub, “A plasticity and anisotropic damage model for plain concrete,” Int. J. Plast., vol. 23, no. 10–11, pp. 1874–1900, 2007, doi: 10.1016/j.ijplas.2007.03.006.
[14] G. D. Nguyen and A. M. Korsunsky, “Development of an approach to constitutive modelling of concrete: Isotropic damage coupled with plasticity,” Int. J. Solids Struct., vol. 45, no. 20, pp. 5483–5501, 2008, doi: 10.1016/j.ijsolstr.2008.05.029.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY