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COUPLED THERMO MECHANICAL OF WASTEGLASS POWDER REINFORCED CONCRETE BEAM SUBJECTED TO FIRE LOADS

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KEY WORDS: ANSYS, contact, finite element model, thermo-mechanical coupling.

ABSTRACT:

Waste Glass Powder (WGP) could be used as a cement replacement additive to manufacture concrete and solving the problem of environmental pollution. This article presents a numerical modeling of the thermo-mechanical behavior of a reinforced concrete beam based on an addition of 20% of the powder glass as a substitute for cement powder with modeling of concrete-steel contact using ANSYS software. To do this, a reinforced concrete beam based on glass powder is modeling in three dimensions by the finite element method (FEM) and it is subject to thermal loading during 2 hours in order to simulate the thermo thermo-mechanical response of the beam element. ANSYS provides a three-dimensional element (SOLID65) with the nonlinear model of brittle materials similar to the concrete materials. The element features a smeared crack analogy for cracking in tension zones and a plasticity algorithm to take into account the concrete crushing in compression zones.

1. INTRODUCTION

Every year, due to global warming, the Earth's temperature rises by a few degrees, leading to a significant increase in the number of wildfires in many regions of the world. The forest fires on August 9, 2021 (photo1), in Algeria had devastating consequences on our region, causing significant damage to homes and businesses. The structural elements of some affected houses were directly exposed to the flames, experiencing the effects of rising temperatures. Under such conditions, reinforced concrete was subjected to thermal stresses, resulting in deformations and subsequent loss of its stiffness and strength.

(a)

(b)

Photo 1 (a,b). The wildfires in Kabylie in June 2021

It is imperative to gain a deep understanding of the behavior of the composite material made of concrete and steel while exploring other more cost-effective and environmentally friendly materials. A promising alternative could be the use of waste glass powder (WGP) as a substitute additive for cement in concrete production, which would contribute to addressing the issue of environmental pollution (Mageswari and Vidivelli. 2010). WGP is a modern and hopeful eco-supplementary cement replacement material that can enhance concrete behavior (Jiang and al., 2019; Abdelli and al., 2020; Elaqra and Rustom, 2018; Niang and al., 2013). The impact of using WGP to partially substitute cement on concrete compressive strength, modulus of elasticity, and creep have been investigated (He and al., 2019; Shayan and Xu. 2006).

The structural fire safety depends on the combustibility and behavior of its main structural elements. The concrete has a good fire resistance due to its low thermal conductivity (Hitesh and al.). (Beitel and Iwankiw, 2004) conducted an international survey of various cases of multi-storey buildings which collapsed (total or partial) due to fire which concluded that RC structures collapsed totally due to the effects of a fire.

They have highlighted although total number of fire events may appear low, these fire events have high consequences with respect to potential for loss of life, injuries and economic loss.

The aims of this study are to simulate a 3D numerical modelling of waste glass powder reinforced concrete beam subjected to fire loads. The strategy calculation based on the FE method will be carried out using code ANSYS 17.1. The transient thermal and structural analysis of the reinforced concrete is aimed at evaluating the materials constitute response of the element beam exposed during 2 hours of load fire equivalent to 200°C. As a current study of this problem, ANSYS simulations with less assumption and less program restrictions have been performed for the thermo mechanical case. Temperature distribution obtained by the transient thermal analysis is used in the calculations of the stresses on the beam element.

2. FINITE ELEMENT MODELING

2.1 Reinforced Concrete beam

In order to modelling the reinforced concrete beam, ANSYS offers us the possibility of introducing the following 3D elements, namely (ANSYS Guide).

(SOLID65) is an eight-node preconized element in reinforced concrete modeling. The nodes of the solid 65 have three degrees of freedom at each node, such as translation in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The node geometry locations for this element type are shown in (Fig. 1 below) and the element link 180 (Shah and al., 1991) corresponding to modelling the steel bars (Fig. 2 below).

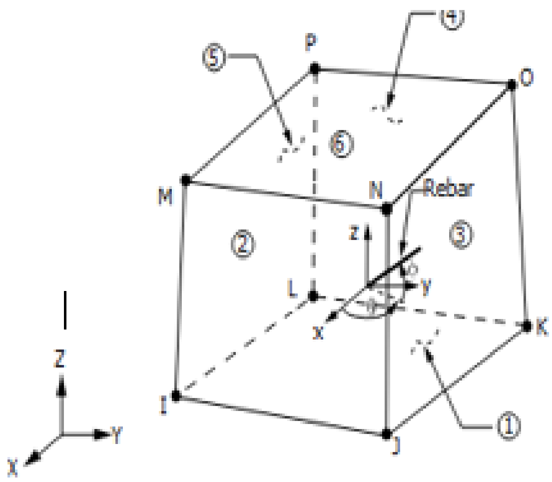

Figure 1. SOLID65 Geometries

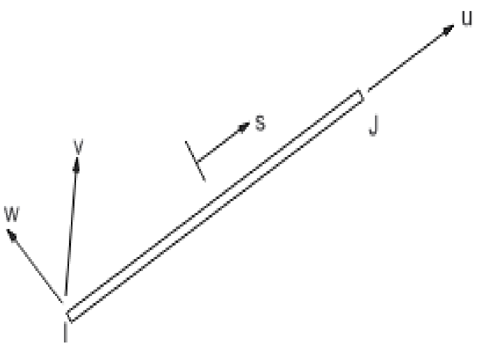

Figure 2. Link 180 Geometries

2.2 Steel Reinforcement

In order to modeling the reinforcing concrete, one of two methods is usually followed. In the first method, the reinforcing is simulated as spar elements with geometric properties similar to the original reinforcing (L. Dahmani and al., 2010). These elements can be directly generated from the nodes in the model. The second idealization of steel reinforcement is the smeared concrete element method (used in this paper). In this case, the concrete and the reinforcing are discretized into elements with the same geometrical boundaries and the effects of reinforcing are averaged within the pertaining element (Fig. 3).

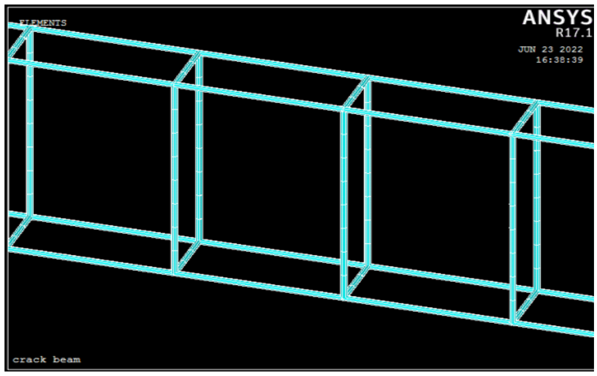

Figure 3. Element reinforced bar

2.3 Contact behavior and Finite element formulation

Using contact elements in a Finite Element Method (FEM) simulation is seldom a simple, painless experience. Changing contact between parts is a common phenomenon which, in some cases, can be treated with rigorous mathematical theory. Formulae for special cases can be found in McGraw-Hill design textbooks (Shigley, 1972; Timoshenko and Goodier, 1970; Chan and Tuba, 1971), two spheres, two parallel cylinders, cylinders on a flat plate, gear teeth, roller bearings, etc. (Kamal Ghouilem and al.,2017). several options and elements governing contact offer us the choice in the development of solutions can significantly improve model performance and reduce analyst frustration with a contact simulation model. Four categories of Contact elements can be grouped such as:

- Node – to Node gap elements: CONTACT12, LINK10, COMBIN40, CONTAC52, CONTA178
- Node – to line (or slide-line) contact elements: CONTAC26
- Node – to –surface contact elements: CONTAC48, CONTAC49
- Node – to –surface contact elements: CONTAC48, CONTAC49
- Surface-to-surface contact elements: TARGE169, TARGE170, CONTA171, CONTA172, CONTA173, CONTA174

The following figure 4 and figure 5 bellow illustrate the cross section details and modelling of contact generation with TARGET169 elements in the Surface-to-surface contact elements between the reinforced bar and the material concrete.

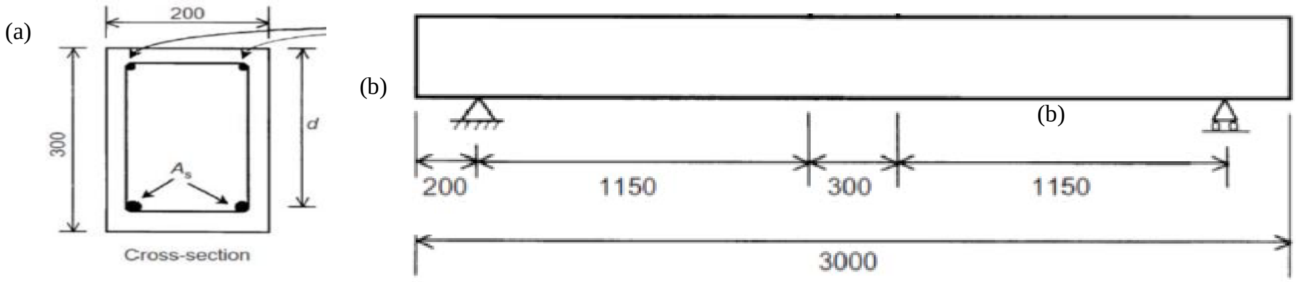

Figure 4 (a, b). Cross Section details of the beam

2.4 Transient thermal Analysis

When performing a time-transient thermal analysis in FEA, it is common to have bulk temperature loads and convective heat transfer coefficients that change values during the transient. Radiation and convection involve heat flow through the structure; conduction involves heat transfer through the body of the structure (Rui Sun and all, 2018). The analysis of transient thermal problems takes into account the three phenomena in which thermal conduction is governed using partial differential equations [1] as:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+Q-\rho c\frac{\partial T}{\partial t}=0 \quad (1)$$

Where; T is the temperature distribution with respect to xyz coordinate, ρ is the material density; k and c represent the thermal conductivity and specific heat, respectively, which are highly temperature-dependent. The specific volumetric heat source Q equals zero since no inherent heat source exists in this case. The initial temperature is needed to solve the differential equation, which can be identified as the ambient temperature at the beginning of the fire test. The effect of heat convection and radiation can be considered using the following surface boundary condition:

The following Eq. (2) states the boundary condition that needs to be satisfied.

$$-k\frac{\partial T}{\partial n}=h\left[T-T_f\right]+\sigma\varepsilon_m\varepsilon_f\left[(T-T_z)^4-\ (T_f-T_z)^4\right] \quad (2)$$

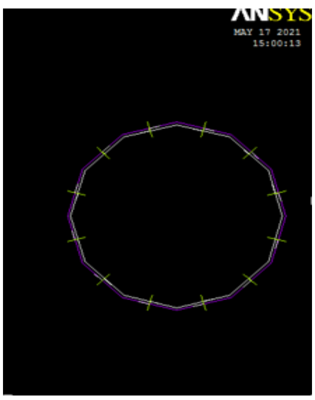

Figure 5. Contact generation between the concrete and reinforced bar

3. COUPLED THERMO MECHANICAL ANALYSIS

3.1 Finite Element model simulation

In this study, a thermo structural analysis of RC beams is performed in two steps: firstly, in thermal analysis model, the concrete beam is discredited with the SOLID 70 elements and the elements LINK 33 (conduction bars) are attributed for the reinforced steel bars (see figures 7 and 8 below). Secondly, in order to launch the structural analysis, ANSYS® offers us the possibility to switch from a thermal analysis to a structural analysis via the command switch element type; we then obtain the corresponding elements namely (SOLID 65 and LINK 180) see figures 1 and 2 above. For the subsequent structural analysis, we take as initial conditions the temperature distributions obtained in the first step. The temperature has been assumed spatially homogeneous. Furthermore, in this article, the Waste Glass Powder concrete is considered as homogeneous material. According to this assumption, the thermal distribution would be uniform along the length of the RC beam. When a structure is exposed to fire, convection, radiation, and conduction phenomena must be considered.

A three-dimensional Finite Element Model simulation (FEM) using the computer program ANSYS® is employed to simulate the response of reinforced concrete beam with Waste Glass Powder, such as displacements, train and shear thermo mechanical results. To create the finite element model in ANSYS® there are multiple tasks that have to be completed for the model to run properly. Models can be created using command prompt line input or the Graphical User Interface (GUI). This section describes the different tasks and entries into used to create the Finite Element calibration model. Analysis by ANSYS® includes two steps, namely a step of modelling and a calculation step.

- The first step is to model the finite element structure by choosing an appropriate item to the type of analysis to be performed, such as for example: As part of this work, we limited ourselves to address the problem in three dimensional finite element discretized by element solid 65 with application of boundary conditions (see figure 6 below). This model, present in this study contains approximate 1280 elements structural see (Fig 6). The 2nd step is divided into three, namely:

  1. Step pre-processor: in this step, we introduce the geometry structural, material properties and Boundary conditions.

2. In the solution phase, we choose the type of analysis.
3. Finally, the results of the completed solution are observed in the post-processing step.

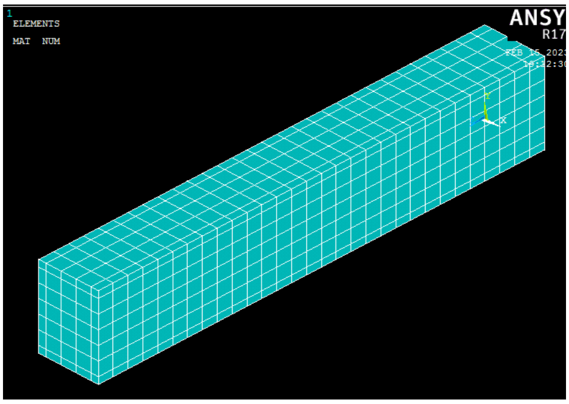

Figure 6. Cross Section modeling of the beam

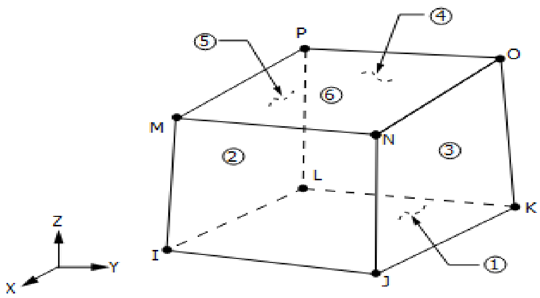

Figure 7. SOLID70 elements Geometry

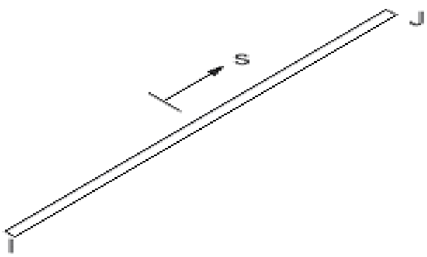

Figure 8. Link 33 elements Geometry

The following table 1 illustrate the materials thermo elastic properties.

Material properties	Concrete	Steel bar
Density, ρ (Kg/m^3)	2310	7850
Thermal conductivity, k (W/m.C)	2	60.5
Specific heat, c (J/Kg.C)	654	434
Poisson's ratio, υ	0.25	0.3
Thermal expansion, α (10-6/C)	6	12
Elastic modulus, E (Pa)	2.10^5	2.10^{11}

Table 1. Thermo elastic properties used in the simulation

4. NUMERICAL RESULTS AND CONCLUSION

The following Figures 9 and 10 illustrate the contour plot temperature distribution and the thermal mechanical strains in the beam during 120 minutes. In the following figure 11 and figure 12, we illustrate the vertical (y) and shear (xy) contour plot thermo mechanical strains respectively. Figure 13 and Figure 14 shows the plot contour stress induced by the fire thermal loading at the upper and lower steel bars.

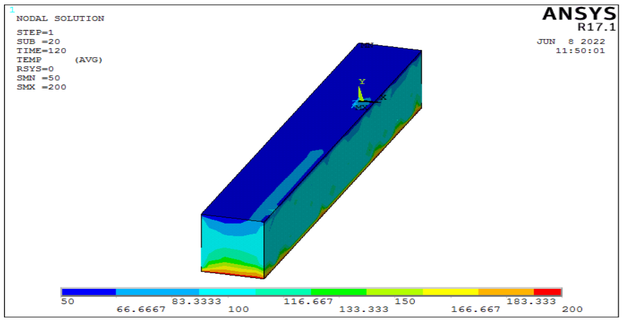

Figure 9. Temperature contour plot in the beam

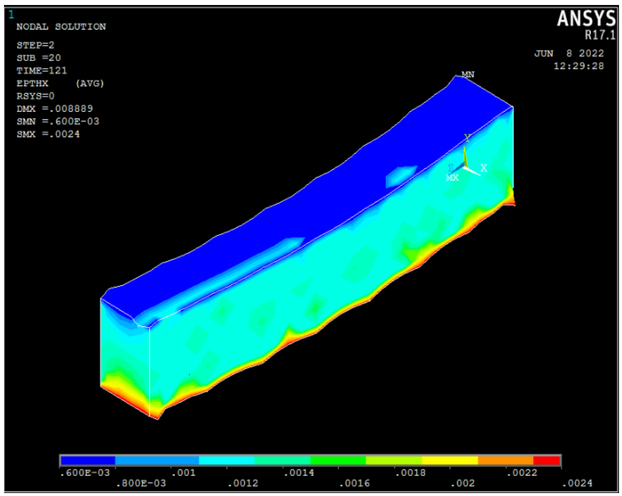

Figure 10. Strain thermo mechanical contour plot

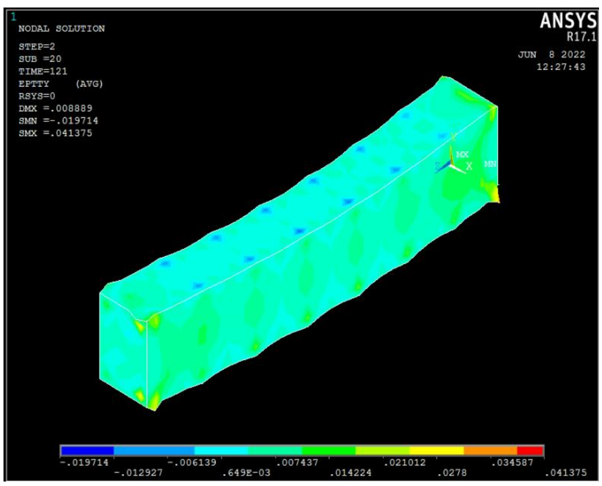

Figure 11. Y Contour plot thermo mechanical strain

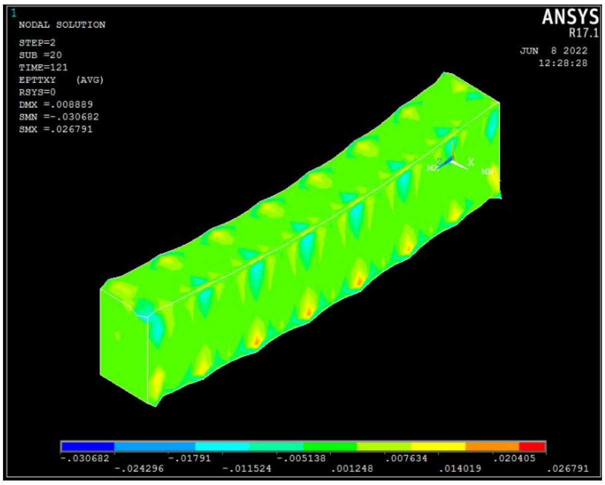

Figure 12. XY Contour plot thermo mechanical strain

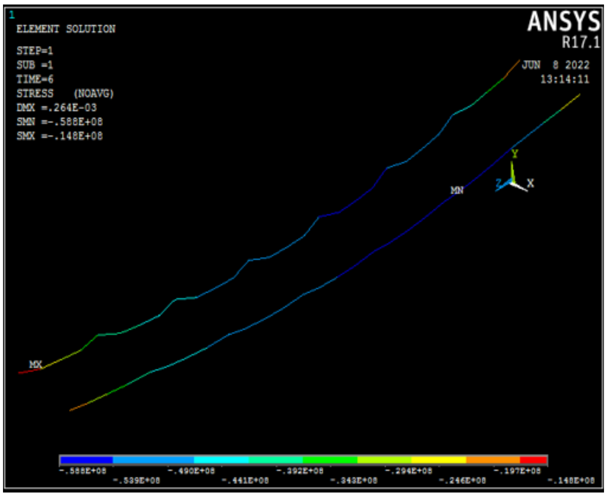

Figure 13. Stress contour plot at the upper steel

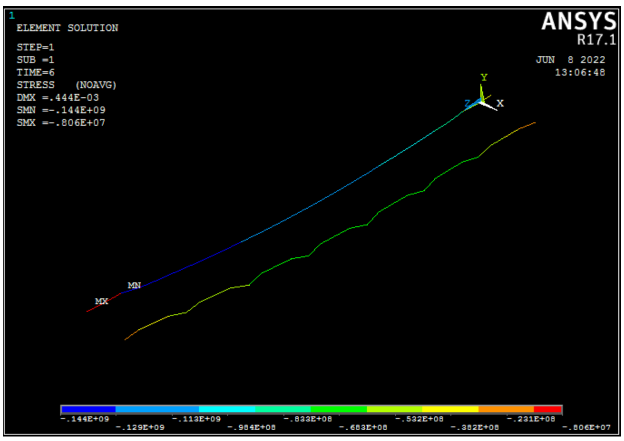

Figure 14. Stress contour plot at the lower steel

Over the past few decades, efforts have been made to develop a rational methodology/procedure for evaluating the behaviour of RC flexural members during fire (CEB-Fib, 2008) .The final results presented in this paper consist in the evaluation of the thermo mechanical response of the elements constituting a concrete beam based on Waste Glass Powder. To evaluate the behavior of RC member under fire, it is required to know the amount of heat ingresses in the member i.e, temperature distribution across the cross section should be known. Heat transfer from the surrounding hot gases atmospheric to the member surface takes place by means of convection and radiation. Within the member heat is transferred through conduction (Hitesh Lakhani and all, 2016).

ANSYS® offers us the possibility to switch from a thermal analysis to a structural analysis via the command switch element type, we then obtain the corresponding thermal elements namely (SOLID 70 and LINK 33) and structural elements namely (SOLID 65 and LINK 180). In this article, an analysis procedure to evaluate the structural response exposed to fire is presented. In this work, this approach is extended and applied to obtain the response of beams under constant load and exposed to fire loads in terms of deflection-time plots. In terms of conclusion, we will say that the thermo mechanical behaviour of concrete based on glass powder is much appreciated; this leads us to better the employee and project it in a new dynamics of construction. In terms of perspective, an experimental analysis is necessary to compare the numerical results against experimental data. This will extend and increase the structure life and preserve the environment.

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