Finite Element Simulation of Fabric Reinforced Cementitious Matrix (FRCM) and Textile Reinforced Mortar (TRM) Bars

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Abstract

Fiber and composite materials are a combination of new materials that result in improving raw materials. Research on composite materials has led to advances in the ability and presentation of new products and they have a special application in civil engineering. In this paper, while introducing two types of composite materials, it is tried to consider their behavior against the incoming force. In fact, the goal is to know more and use (FRCM) and (TRM) fiber to improve, strengthen, and fortification of the structures. Using the laboratory tested model of the reference paper as a reference, and measuring it with the created models of a concrete beam based on this type of fiber in ABAQUS software and for better understanding, parameters such as displacement curve diagram, final load rate, layer thickness, how to strengthen the configuration, energy amortization, structural stiffness, and surface cracks will be analyzed.

Keywords: Fabric Reinforced Cementitious Matrix (FRCM); textile reinforced mortar (TRM); concrete bar; static nonlinear analyses; performance parameters; concrete bar

1. Introduction

Cement composites can be classified according to the type of used fiber. But this is not usually done. They are often classified based on geometric arrangements and fibers. Figure 1 summarizes the classification generally used for BMCs following definitions of mechanical behavior and types of applications.. This overview sought to provide a framework for FRCM composites studied in this paper (ASTM C1275 2010).

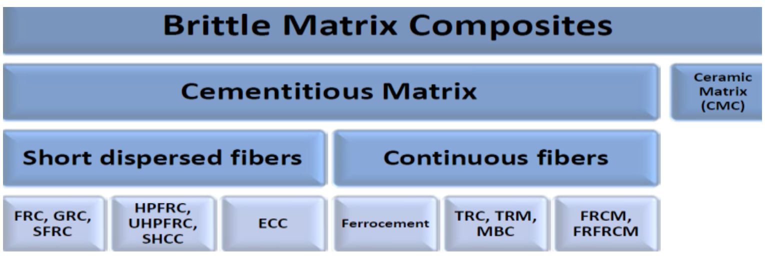

Figure 1 - A summary of the classification for BMCs in general

Both TRC and FRCM are new technologies with a high potential in civil engineering, in which several projects are in progress. Since the mortar matrix used for continuous reinforced composites can be

reinforced by dispersed short fibers (a combination of short and continuous reinforcement), the term fabric-reinforced cementitious matrix (FRCM) is used which is not common. Cementitious composites are compared with fiber-reinforced polymer composites in which the polymer matrix is replaced by a matrix based on minerals or inorganic materials; this, in thurn, creates another term called mineral-based composites (MBC). Another term commonly used for this composite is mortar or textile-reinforced mortar (TRM), which examines the term textile-reinforced mortar (TRM) versus fibers-reinforced polymers (FRP) in shear reinforcement of concrete bars . (Al-Salloum, Y. A., Elsanadedy, H. M., Alsayed, S. H., & Iqbal, R. A. (2012).
Fiber reinforced composites have been widely used to strengthen reinforced concrete (RC) members since they have a high strength-to-weight ratio, require relatively limited time to cure, and have mechanical properties that can be engineered to meet the desired structural performance. Fiber-reinforced polymer (FRP) composites, which are comprised of continuous fibers (usually carbon, glass, or aramid) and a thermosetting (organic) resin, are currently the most common type of composite system used for structural strengthening applications. Another type of composite that was recently developed is referred to as fiber reinforced cementitious matrix (FRCM) composite, which contains continuous fibers with a cementitious (inorganic) matrix. The use of inorganic matrix was proposed to address some of the inherent disadvantages associated with the use of organic resin in FRP composites, such as lack of moisture vapor transmission. (Babaeidarabad, S., Arboleda, D., Loreto, G., & Nanni, A. (2014).

A new class of composites that is being explored includes steel fiber sheets with either an inorganic matrix or an organic matrix described above. The use of steel fibers was proposed as a lower-cost alternative to other fiber types used in FRCM or FRP composites such as carbon, aramid, glass, or polyparaphenylene benzo-bisoxazole (PBO). The resulting composites have been referred to in the recent literature by different names, but are herein referred to as steel-FRCM and steel-FRP, respectively. Published literature on steel-FRCM and/or steel-FRP composites dates from 2004. Different authors have studied the use of steel-FRCM and/or steel-FRP for flexural strengthening of RC beams and RC slabs. These studies have shown that steel-FRCM and steel-FRP composites are effective in increasing the flexural strength of the member, although debonding of the composite tends to limit the effectiveness except in cases of relatively low fiber density where fiber rupture has been observed. Experimental evidence in the literature reports that debonding of steel-FRCM composite can occur within the composite instead of within a thin matrix-rich layer of the concrete substrate as is typically the case with FRP composites. Interestingly, the limited numbers of studies that have investigated mechanical anchorage of steel-FRCM composites have shown that anchorage did not significantly improve the performance of the strengthening system. Therefore, for design purposes it is important to under-stand the debonding process and potential factors that may help mitigate this mode of failure. (ACI Committee 549. (2015)

This paper presents the results of an experimental investigation conducted to study the flexural response of RC beams strengthened using externally bonded steel-FRCM composite. Steel-FRCM composite strips were bonded to the tension face of four RC beams, which were tested in four-point bending. Parameters varied were the presence/absence of the external (coating) layer of matrix, presence/absence of U-wrap anchorages, and loading rate. The strengthened beam load responses are presented and compared, and the contribution of the composite to the flexural strength is examined. Debonding of the steel-FRCM composite strips is also discussed. Results are compared with those from single-lap direct-shear tests conducted on the same composite. In general, there are three methods for solving physical problems: precision analysis, numerical and experimental methods. Here we use a numerical method by Abaqus software, which is the most practical method used in solving engineering problems. As mentioned, the finite element technique is used in various structural, vibration, thermal, etc. issues. In the finite element model, the final charge of Pu, elastic stiffness (K), as well as the depleted energy of the structure (E) and the amount of damage caused by cracking, input values (loading and boundary conditions) and output (results), are assigned to them. Each element has a behavior such as the degree of freedom (for example, u displacement), the appropriate shape, the ability to satisfy boundary conditions, the specifications of materials and internal stresses in terms of displacement, external forces and plant-based conditions at the locations of nodes and equilibrium equations of the whole system are obtained. After the exact implementation of the model in the software, the precise calculation values are extracted from it. (Mechtcherine, V. (2013).

2. Numerical simulation of reference model in software

After entering to the software in the initial stage of simulation aiming at to remove adjacent components and excessive geometric complexities in the concrete beam structure, the accuracy of the simulation and its compliance with laboratory conditions will be carried out. According to the information provided in the reference paper, in the laboratory testing program, a concrete beam sample with a length of 2 meters and a rectangular section of 250mm×150 mm has been studied. Transverse steel rebars have been used asymmetrically to cause damage to one side of the beam (left side of the beam). Also, all concrete beams have a network of internal bending and shear reinforcements (armatures), which are designed to provide beam shear strength. Steel tensile reinforced reinforcement consists of three rebars with a diameter of 20 mm. Also, reinforcements with a diameter of 6 mm were used to reinforce transversely the concrete beam. The compressive strength of concrete f'_c= 30 MPa and the yield stress of steel reinforcements are assumed to be equal to f'_c= 30MPa. As shown in the following figure, the laboratory model layout of the studied concrete beam is shown (Figure 2): (Loreto, G., Leardini, L., Arboleda, D., & Nanni, A. (2014).

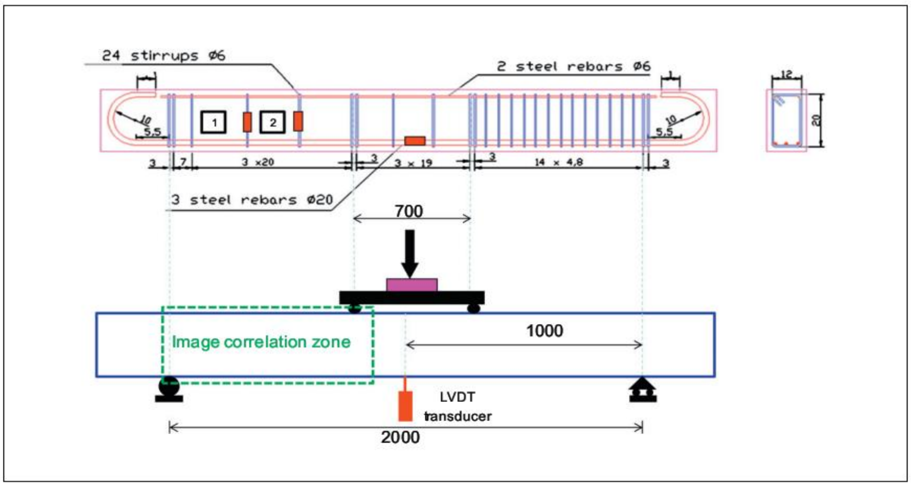

Figure 2 - Laboratory model of reference concrete beam

3. Specifications of reinforced concrete beam

After modeling the reference beam in ABAQUS software, and adapting it to the laboratory output results, including the load-displacement diagram and in order to validate the numerical model, it is observed that there is a difference of 3.79% in calculating the maximum tolerable final load of concrete beams which indicates the correct accuracy of the results and therefore the numerical analysis method is verified with the help of ABAQUS software. As a result, this method of numerical analysis is suitable for simulating the performance of other studied concrete beam models and will be used in the following research. is shown below .(Figure 3)

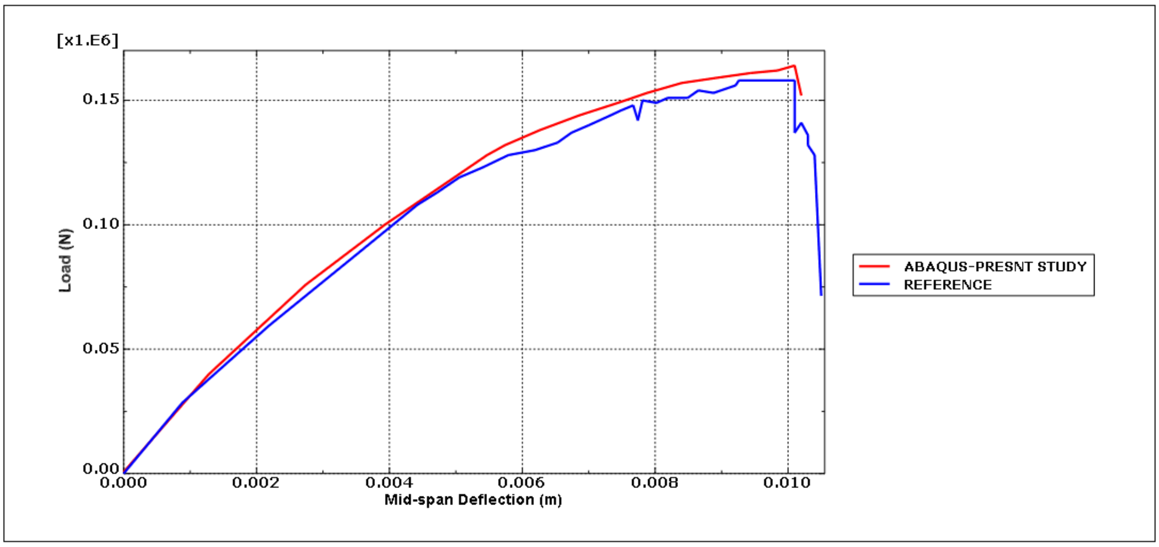

Figure 3 - Comparison of load diagram – displacement of reference concrete beams and numerical model in ABAQUS software

As mentioned in the previous sections of this study, in this research, the reinforcement of concrete beams will be evaluated using TRM and FRCM composite materials. For this purpose, according to the following figures, the reinforcement of concrete beams is examined using different models and their effect on the performance of concrete beams. A three-part format is used to name the models, the first part expressing the type of model, the second part expressing the type of reinforcing materials, and the third part expressing the thickness. In this part of the research, the specifications of reinforced concrete beams with TRM and FRCM materials with thicknesses of 5, 10, 15 and 20 mm can be created in ABAQUS software, and the paper according to the table below with a constant thickness of 10 mm will be paid attention. Shown in the following And table figures. .(Shown in the following figures 4.5.6. and the table 1 below)

Table 1- Specifications of reinforced concrete beams

Model	Specifications	Coating thickness
FLAT-TRM-10	TRM reinforced concrete beam model with flat pattern	10 mm
STRIP-TRM-10	TRM reinforced concrete beam model with STRIP pattern	10 mm
U-TRM-10	TRM reinforced concrete beam model with U pattern	10 mm
FLAT-FRCM-10	FRCM reinforced concrete beam model with FLAT pattern	10 mm
STRIP-FRCM-10	FRCM reinforced concrete beam model with STRIP pattern	10 mm
U-FRCM-10	FRCM reinforced concrete beam model with U pattern	10 mm

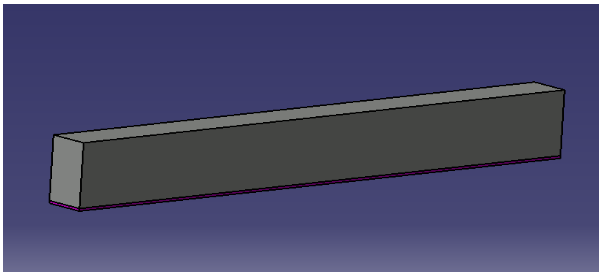

Figure 4 - Reinforcement of the lower side of concrete beams with TRM and FRCM materials

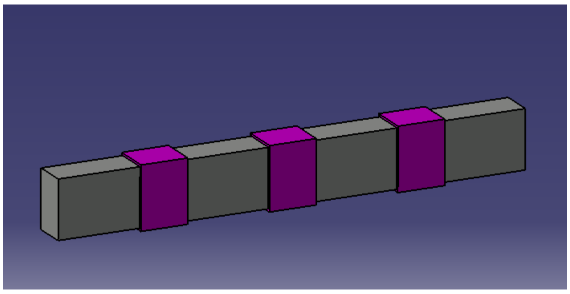

Figure 5 – Strip reinforcement of concrete beams with TRM and FRCM materials

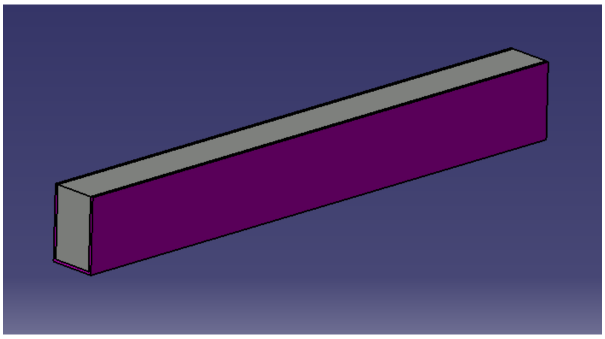

Figure 6 . Reinforcement of concrete beams with a U-shaped model of TRM and FRCM materials

4. The Analysis of reinforced concrete beam model by FRCM

After performing the model, and numerical analysis of the software, the concrete beam models reinforced by FRCM based on the presented diagrams, including force-displacement curves, Pu final load calculation, elastic stiffness (K) as well as dissolved energy of the structure (E) and the amount of damage caused by cracking will occur. This can be very important in seismic areas where the goal is to increase the plasticity and depreciation of the structure. The following figures show the force-displacement curves of reinforced concrete beams by FRCM.(Figure 7)

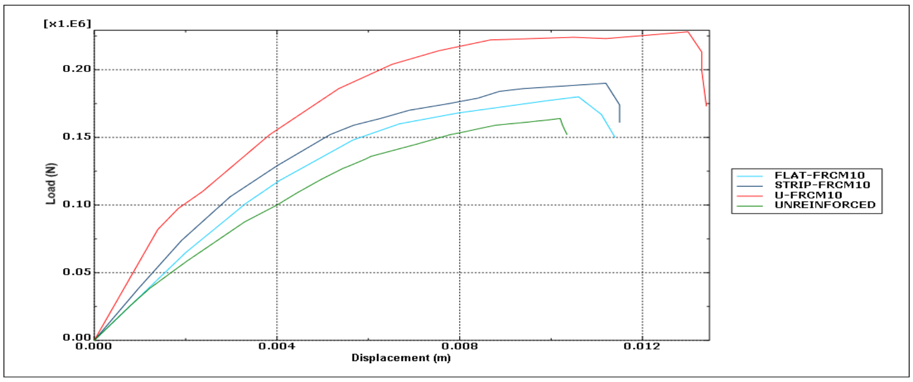

Figure 7 . The effect of reinforcing concrete beams with different FRCM patterns on the load-displacement curve

The tolerable final power for the U-FRCM10, STRIP-FRCM10, and FLAT-FRCM10 models is 228KN, 191KN, and 182KN, respectively. However, the unreinforced concrete beam shows a final resistance of 164KN. Therefore, it can be concluded that the U-shaped pattern in the best case increased the final strength of the wall significantly by 28.07% .(Table 3)

Table 3. FRCM tolerable final strength for reinforcing concrete beams

Specimen	P_u (KN)
U-FRCM10	228
STRIP-FRCM10	191
FLAT-FRCM10	182
UNREIFORCED	164

The results of the analysis show that the amount of elastic stiffness of the structure is equal to K =58.92 KN/m ، K =38.64 KN/m ،K = 32.40 KN/m respectively. In unreinforced concrete beams, the amount of elastic stiffness K = 29.76 KN/m has been calculated. It is therefore obvious that the increase in structural elasticity of the structure with the U-shaped FRCM model is greater.(Shown in the tables 4.5 below)

Table 4- Elastic stiffness changes of different FRCM patterns to strengthen concrete beams

Specimen	K $(\frac{KN}{m})$
U-FRCM10	58.92
STRIP-FRCM10	38.64
FLAT-FRCM10	32.40

UNREIFORCED	29.76

Table 5- Energy dissipation changes in different FRCM models for reinforcing concrete beams

Specimen	**E** (**Kj**)
U-FRCM10	2.22
STRIP-FRCM10	1.59
FLAT-FRCM10	1.31
UNREIFORCED	1.17

In the table below, the amount of damage caused to the concrete beam is shown. The U-FRCM10 model has had the greatest impact on reducing the damage caused by tensile cracks in the concrete beam.(Table 6)

Table 6- Damage caused in reinforced concrete beams with different models

Structure	DAMAGE T (%)
Concrete beams	0.99
U-FRCM10	0.41
FLAT-FRCM10	0.67
STRIP-FRCM10	0.48

And in the final part of the structure, the effect of using FRCM materials on the amount and shape of tensile cracks in concrete beams has been studied. For this purpose, the following forms of contour traction damage due to cracking (DAMAGE T) are shown in Abaqus software.(Shown in the Figures 8.9.10.11 below.)

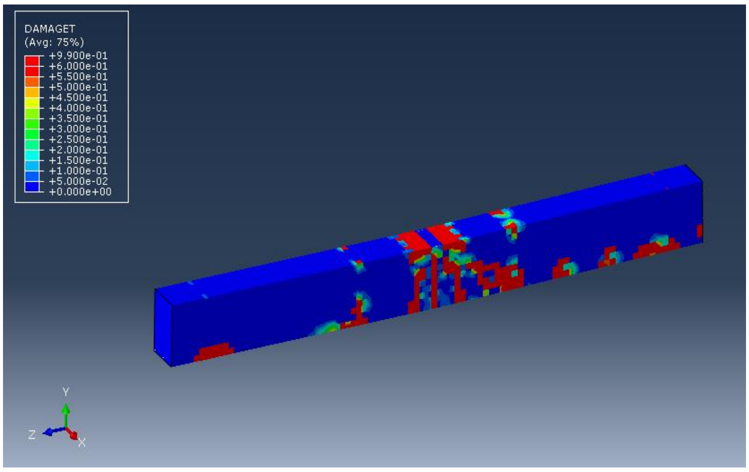

Figure 8- Damages caused by cracking of concrete beams at the end of the loading

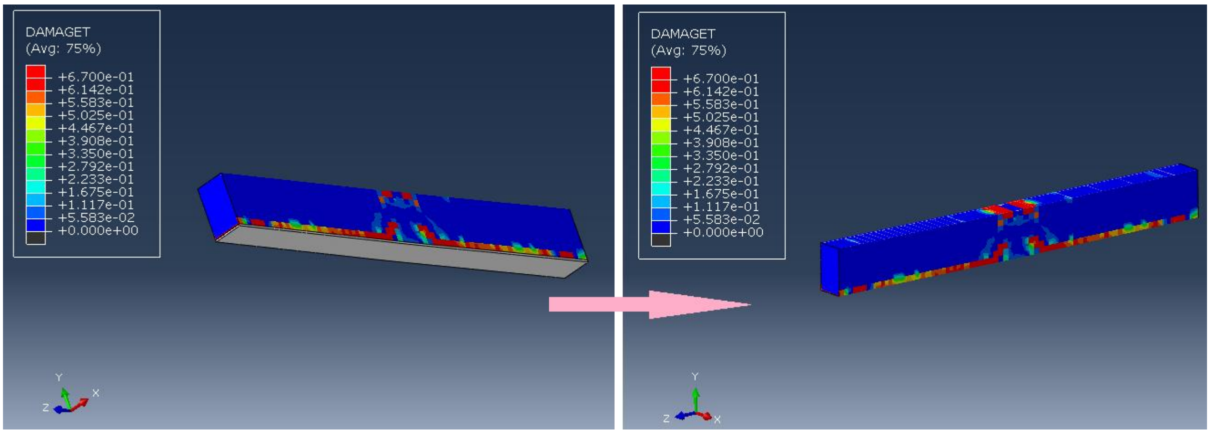

Figure 9- Reduction of damage caused by cracked reinforced concrete beams FLAT-FRCM10 at the end of the loading

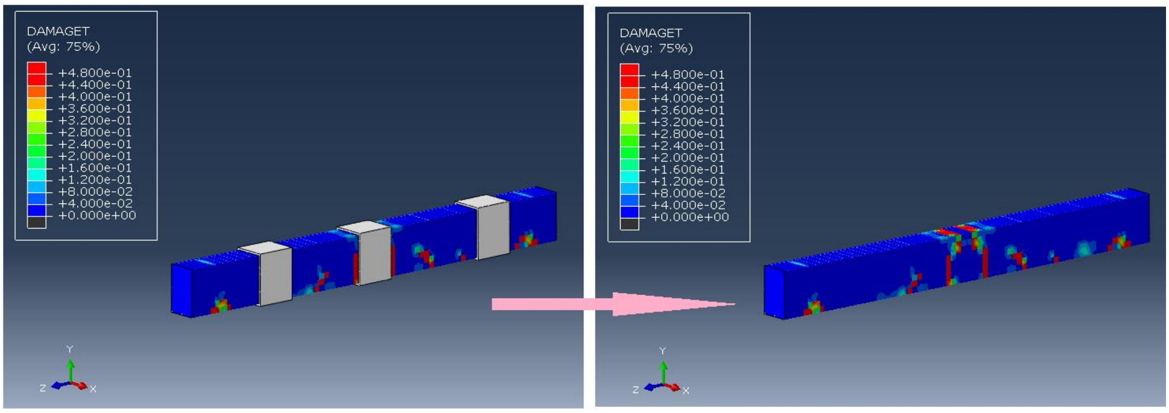

Figure10- Reduction of damage caused by cracked reinforced concrete beams STRIP-FRCM10 at the end of the loading

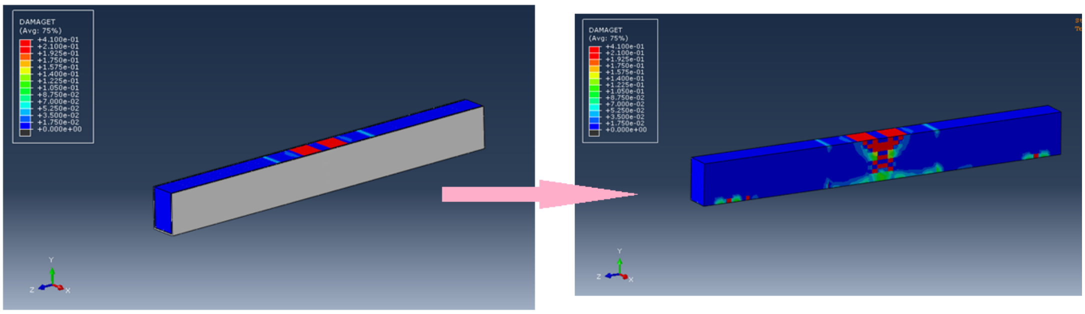

Figure 11 - Reduction of damage caused by cracked U-FRCM10 reinforced concrete beams at the end of the loading

5. The Analysis of reinforced concrete beam model by TRM

After performing numerical analysis of concrete beam models reinforced by TRM, the final load of P_u, elastic stiffness (K), as well as the depleted energy of the structure (E) and the amount of damage caused by cracking, will be calculated based on the diagrams, including force-displacement curves. In the continuation of the research, the behavior of reinforced concrete beams is shown with different reinforcement patterns by TRM materials and comparison with TRM reference beams: (Figure 12).

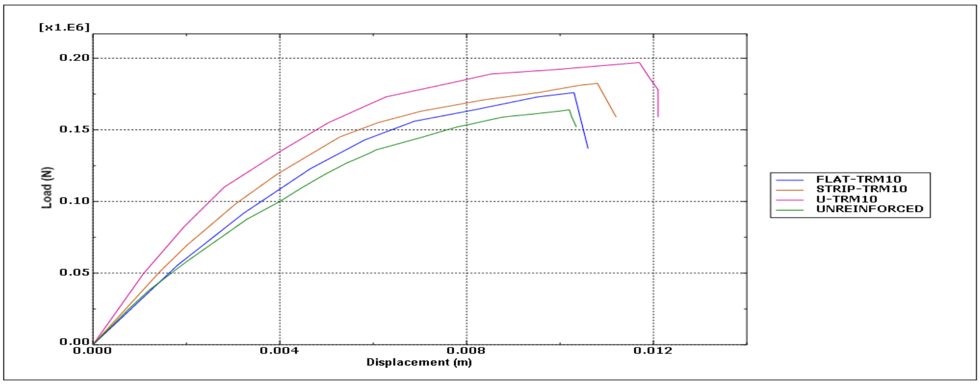

Figure 12 . The effect of reinforcing concrete beams with different TRM patterns on the load-displacement curve

In beams reinforced with TRM materials, the tolerable final force for the U-TRM10, STRIP-TRM10, and FLAT-TRM10models is 197KN, 182.5KN, and 176KN, respectively. However, the unreinforced concrete beam shows a final resistance of 164KN. The results show that the U-shaped model is the most suitable shape to increase the final strength of the concrete beam by 20.12%. (Table 7)

Table 7- TRM tolerable final strength for reinforcing concrete beams

Specimen	P_u (KN)
U-TRM10	197
STRIP-TRM10	182.5
FLAT-TRM10	176
UNREIFORCED	164

Also, the results of the analysis show that the amount of elastic stiffness of the structure is equal to ، K =45.93 KN/m , K= 35.62 KN/m , K= 30.66 KN/m respectively, and considering unreinforced concrete beam, the amount of elastic stiffness which is K = 29.76 KN/m has been calculated. It is therefore obvious that the increase in structural elasticity of the structure with the U-shaped TRM model is greater.(Shown in the tables 8.9 below)

Table 8- Changes in elastic stiffness of different TRM patterns to reinforce concrete beams

Specimen	K $(\frac{KN}{m})$
U-TRM10	45.93
STRIP-TRM10	35.62
FLAT-TRM10	30.66
UNREIFORCED	29.76

Table 9- Energy dissipation changes of different TRM models for reinforcing concrete beams

Specimen	E(Kj)
U-TRM10	1.69
STRIP-TRM10	1.41
FLAT-TRM10	1.24
UNREIFORCED	1.17

In the research, the effect of using TRM materials on cracking damage in concrete beams has been studied. Comparing the damage contours in concrete beams, it seems that the use of TRM materials with different patterns has had a significant effect on reducing the amount of damage. Also, the use of a U-shaped model of TRM materials has had a more favorable effect on reducing the damage caused by the cracking of concrete beams .(Shown in the following figures 13.14.15.16. and the table 10 below)

Table 10- Damage caused to reinforced concrete beams with different TRM models

Structure	DAMAGE T (%)
Concrete beams	0.99
U-TRM10	0.45
FLAT- TRM 10	0.72
STRIP- TRM 10	0.54

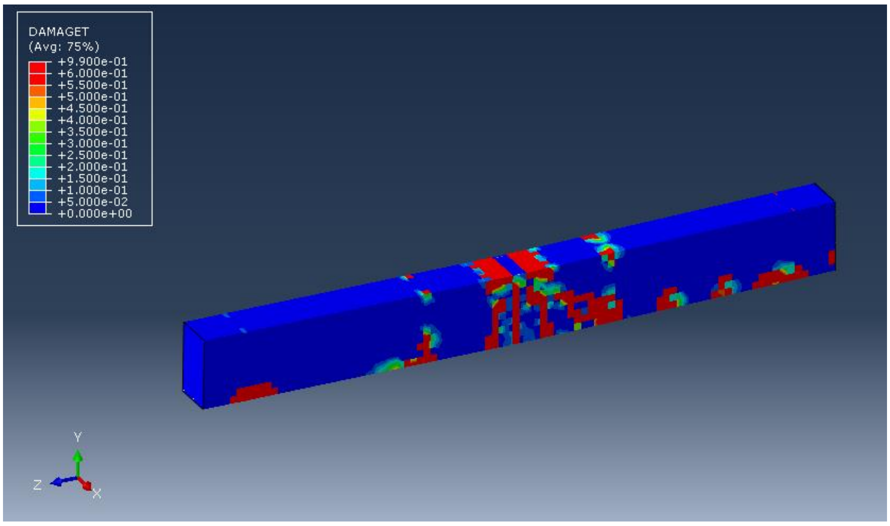

Figure 13- Damages caused by cracking of concrete beams at the end of the loading

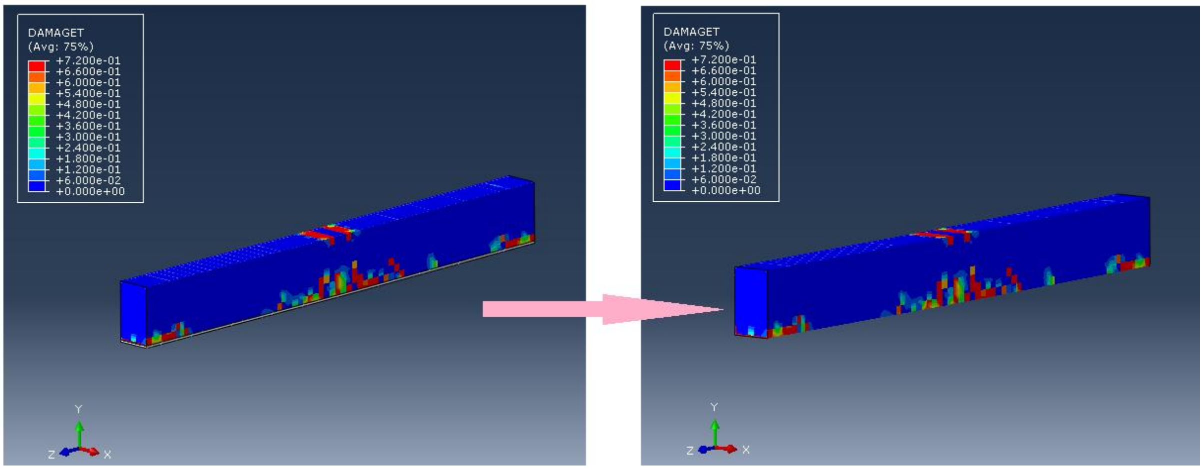

Figure 14- Reduction of damage caused by cracked reinforced concrete beams FLAT-TRM10 at the end of the loading

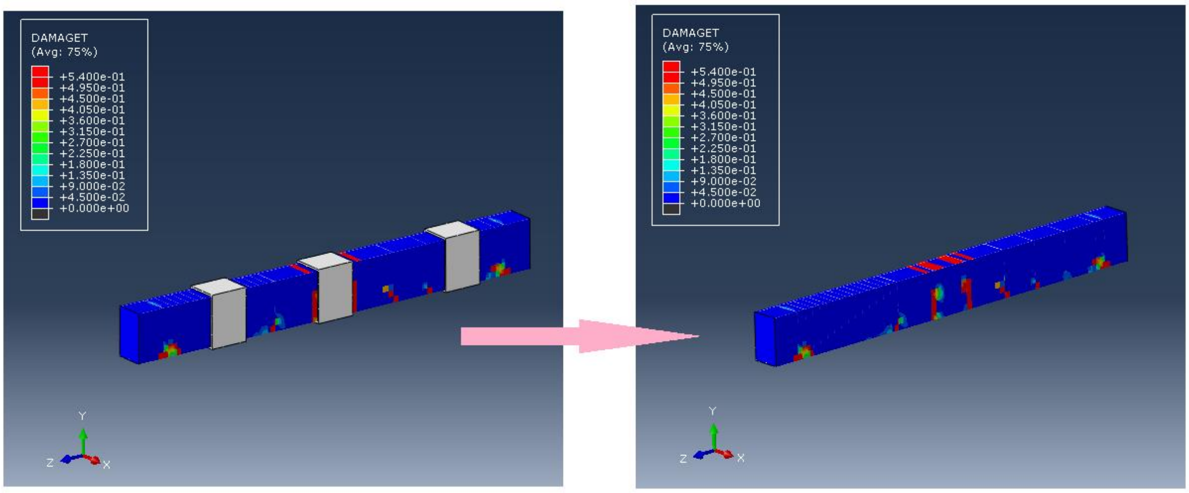

Figure 15- Reduction of damage caused by cracked reinforced concrete beams STRIP-TRM10 at the end of the loading

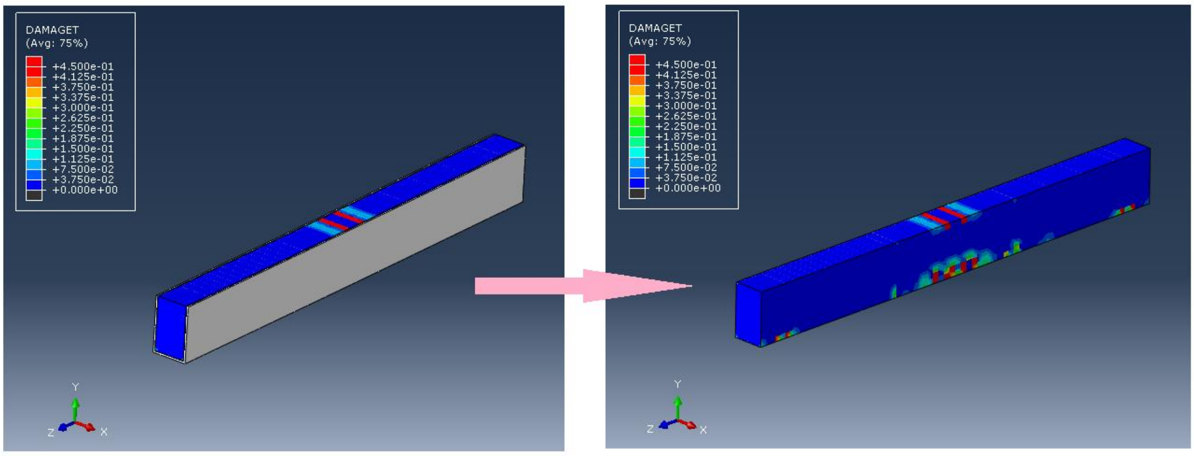

Figure 16- Reduction of damage caused by the cracking of reinforced concrete beams U-TRM10 at the end of

the loading

6. The results at a glance

Comparison of the resulting sample based on diagrams including force-displacement diagrams, calculation of final P_u load, elastic stiffness (K) as well as depreciated energy of the structure (E) and the amount of damage caused by cracking, we can understand that by increasing the thickness of the reinforcing concrete beam, the performance of concrete beam improves which it is recommended to use the U-shaped model. The following bar charts show a comparison between the use of TRM and FRCM materials to reinforce concrete beams. It can be seen that in all concrete beam reinforcement patterns, the use of FRCM has a more favorable effect than TRM. .(Shown in the Figures 17.18.19 below.)

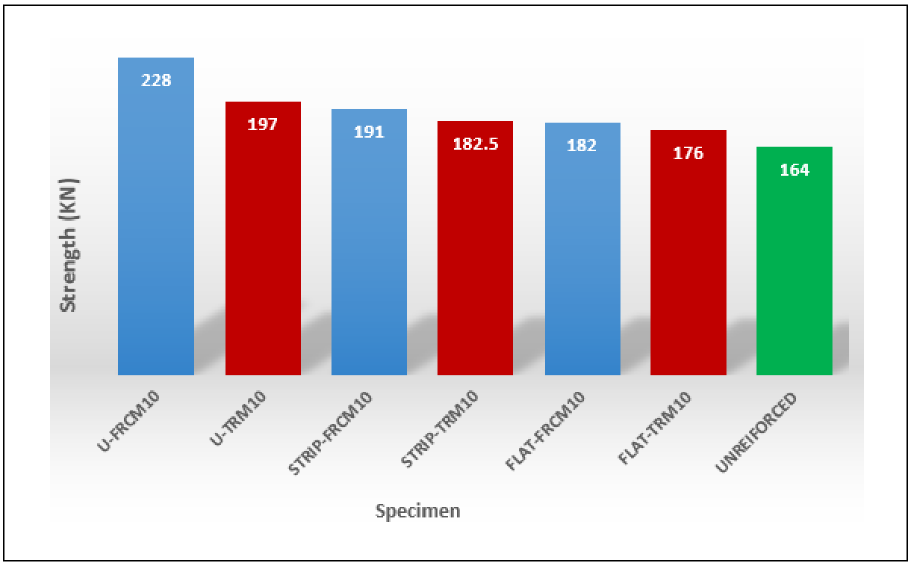

Figure 17. Comparison of the tolerable final load of TRM and FRCM for reinforcing concrete beams

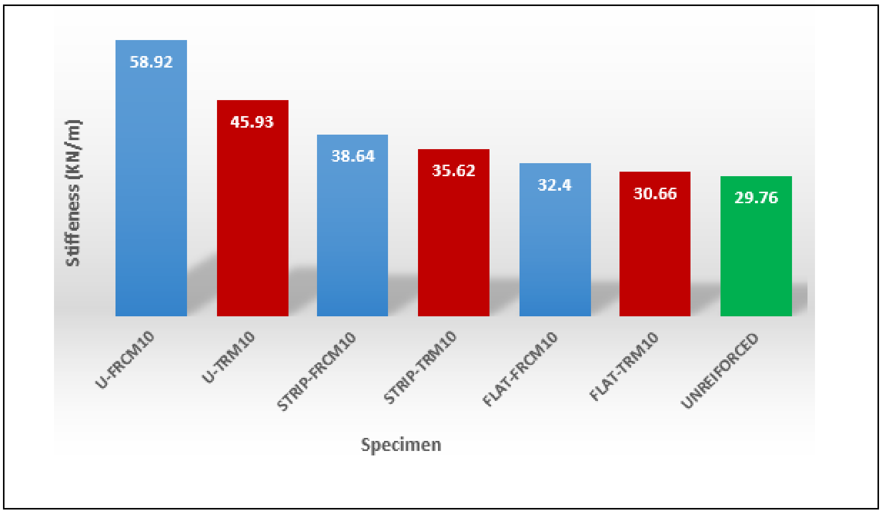

Figure 18 - Comparison of elastic stiffness of different TRM and FRCM patterns for reinforcing concrete beams

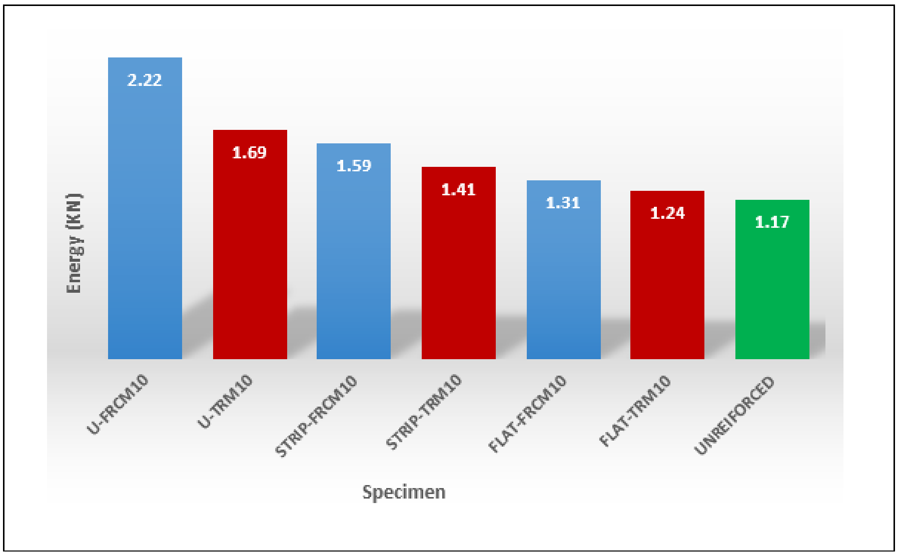

Figure 19 - Comparison of energy dissipation capability of different TRM and FRCM models for reinforcing concrete beams

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