Journal of Physics: Conference
Series

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To cite this article: E A Lofty *et al* 2023 *J. Phys.: Conf. Ser.* **2616** 012048

Flexural investigation of a composite trussed-beam for aerospace shelters using numerical modelling

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Abstract. The composite beams used in aerospace shelters are always exposed to many problems such as: expensive repairing and maintenance costs, and low durability. This research aims to investigate the effect of reinforcing hybrid composite beams with embedded steel-angle truss system (Trussed-beam) inside concrete cover to be used in aerospace structures and shelters. Foremost, a reliable finite element (FE) model was conducted to verify a previous experimental result of a trussed beam, using ABAQUS software. Then, a parametric study was conducted to optimize several parameters, using the reliable FE model. Six composite trussed-beam specimens were modelled to investigate the ultimate flexural capacity. Load-displacement curve was utilized to measure the flexural capacity of the beams. Based on the results obtained from the current study, the composite trussed beam, which is web reinforced by inclined steel Plates, with angle of inclination of 45 degrees obtained significant results relative to the traditional reinforced concrete beam. These hybrid composite beams' flexural behaviour was significantly improved by increasing their compressive strength.

***Keywords**:* Embedded truss, composite beams, steel-angle truss, aerospace shelters.

1-Introduction

Recently, many researches have been concerned in enhancing the performance (ultimate flexural and shear capacity) of reinforced concrete (RC) beams. Many approaches were used to investigate the enhancement in the RC beams, such as using high performance concrete (HPC), ultra-high-performance concrete (UHPC), prestressed concrete (PC), fiber reinforced polymers (FRP), etc. Most of these methods are related to material enhancement. Moreover, it is expensive and need complex requirements [1]. In the last decade, Hybrid steel truss reinforced concrete beam (HSTRCB) was developed In Europe. It was widespread due to its low cost, ease of fabrication and its great effectiveness in light constructions[2].

Tesser et al [3] investigated the behaviour of embedded truss beams in shear and flexural experimentally. The model was composed of steel plate, acts as truss bottom chord, two steel welded bars act as upper chord and inclined steel bars (one end welded to upper bars and the other end welded to the steel plate) acts as diagonal chords. The experiments showed that the bottom reinforcement suffered buckling.

colajanni et al [4] used pushout tests to study the mechanism of stress transformation between embedded truss reinforcement and concrete in tesser's model. Brittle failure occurred for the specimens as concrete failed in tension but no damage occurred in welding.

colajanni et al [5] Used three point bending test and finite element models using ABAQUS to develop an equation. This equation predicts the shear behaviour of embedded truss steel in reinforced concrete beams.

Non zhang et al [6] tested specimens, consists of steel-angle truss embedded in the core of traditional reinforced beam .The results showed significant effect on the shear behavior of small shear span to depth ratio.

Kareemi et al [6] proved the effective shear performance of truss reinforced concrete beams by testing eight specimens subjected to distributed load.

Ballarini et al [7] concluded that flexural failure occurred in steel trussed-beams of large sizes while shear failure occurred in that of small sizes by simulating that beams under three-point bending test by using Abaqus.

kun wang et al [8] studied, experimentally and numerically, the flexural performance of steel tube truss reinforced concrete beams, under 3-point bending test. A parametric study was carried out to test the effect of the compressive strength of concrete and steel ratio on the performance of the beam.

This research presents the flexural behaviour of HSTRCB. The truss is composed of two steel angles representing the lower chords, two steel angles representing the upper chords and thin plates represent the web reinforcement. HSTRCB are numerically tested under three-point bending, using Abaqus. Failure loads and the corresponding maximum deflections were compared to traditional reinforced concrete beam with the same area steel to concrete ratio. Then a parametric study was carried out to test the effect of the spacing between diagonals and their positions on the flexural performance of HSTCB.

2. Validation of the FEA Models Using Abaqus

The numerical established model were verified by comparing the results obtained experimentally by N. Zhang et al [1]. The aim of the verification is to build a trusted model before starting the parametric study. N. Zhang experimentally tests five specimens to study the effect of adding embedded steel truss on the shear performance of concrete beams. The tested specimen is reinforced by both steel angles and reinforced rebar. The bottom longitudinal rebar is 3Ø22 with yield stress of 393 MPa. The Top longitudinal bars are 2Ø16 with yield stress of 378 MPa. Stirrups are Ø8 @ 150 with yield stress of 368 MPa. Embedded truss reinforcement was added to increase the strength of the beam. The yield stress of the truss is 345 MPa. This embedded truss system is composed of steel angles. The lower steel angles are 40x40x4 mm. The upper angles are 30x30x4 mm. Batten plates 30x4 mm were added as web reinforcement as shown in Figure 1.

To build the FEA model all the component parts of the beam were drawn separately. These components were collected and added to the assembly. The material properties of the concrete, longitudinal steel bars and steel angles were defined as in the material properties of Zhang's model. The young's modulus of steel parts is 200 GPa. Poisson's ratio is 0.3. Two types of sections were developed to be assigned to different beam parts. First, homogenous solid section for concrete host beam, embedded steel truss, steel angles and batten plates. Second, truss section for reinforcement steel bars.

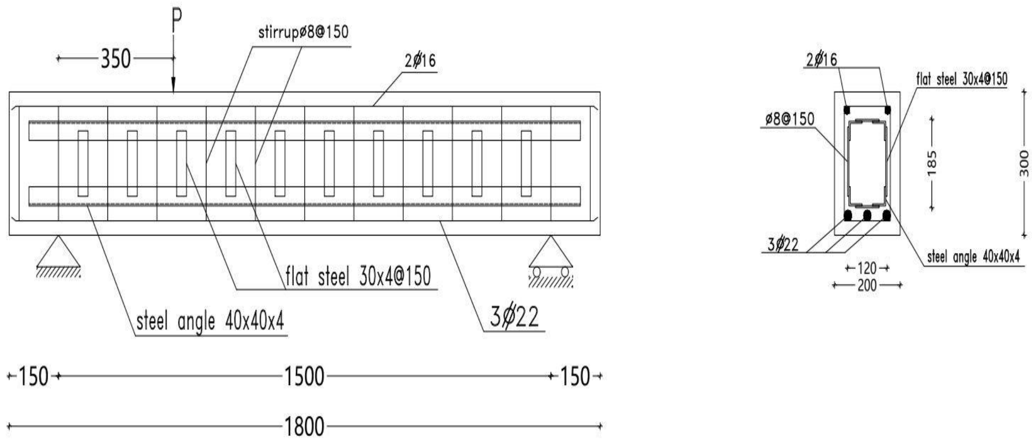


Figure 1. longitudinal and cross section of the tested specimen [1]

Defining material properties is considered one of the most important stages in building a trusted finite element model. For the elastic concrete behaviour, the concrete compressive strength is 44.11 MPa and Poisson's ratio is 0.2. Concrete Damage Plasticity (CDP) was used to model the inelastic behaviour of the concrete material. CDP is generally used to model concrete subjected to failure caused by either the cracks in tension zones or crushing in compression zones. Steel parts used in the FEA models have modulus of elasticity 200 MPa. The yield strength for Ø8, Ø16, Ø18, and the truss angles were 240, 360, 360, 350 MPa. respectively.

In Step stage we defined two types of Steps. Initial step, for defining the interactions between different model parts and the boundary conditions. Static General Step which is used to define the static point load acted on the tested specimen. It was very important to decrease the size of incrimination of the static step to divide the loading of the specimen to many incriminations, small steps, to be able to study the changes occurred in the specimen under loading. This size was chosen carefully to ensure the convergence state during solving the model. Within this stage the studied fields were chosen in the Output History Manager throughout the incrimination interval [9].

There are many approaches to simulate the interaction between concrete and steel parts in ABAQUS. However, the best approach is the embedded region where the Concrete beam was considered as host region while the embedded steel parts were chosen as embedded region. The advantage of this type of interaction approach is that it makes the reinforced steel harmonious with the surrounding concrete. Although this approach is time consuming but it significantly simulates the experimental results [10]. Surface to surface contact was used to define the weld between the steel angles and batten plates of the embedded truss. The friction coefficient in tangential behaviour was taken 0.15 and the normal behaviour was defined as hard contact [11]. This simplified contact modelling achieves acceptable results and overcomes the failure that might happen in the welding between steel elements as the experimental results.

The boundary conditions were determined in the initial step. The load application increment was displacement control by 8 mm in the U2-direction. Finite element meshing process has several methods depending on the type of the part and its section properties. For plain concrete beam and truss sections, the elements were 3D stress (C3D8R) while truss type (T3D2) was chosen for steel bars. Mesh sensitivity analysis was performed to verify that the FE model has converged to a solution. It also provides a justification for the mesh independence. Hence, additional mesh refinement is not necessary. For computational time saving, the largest mesh size was chosen as 25 mm after testing the mesh sensitivity as shown in Figure 2.

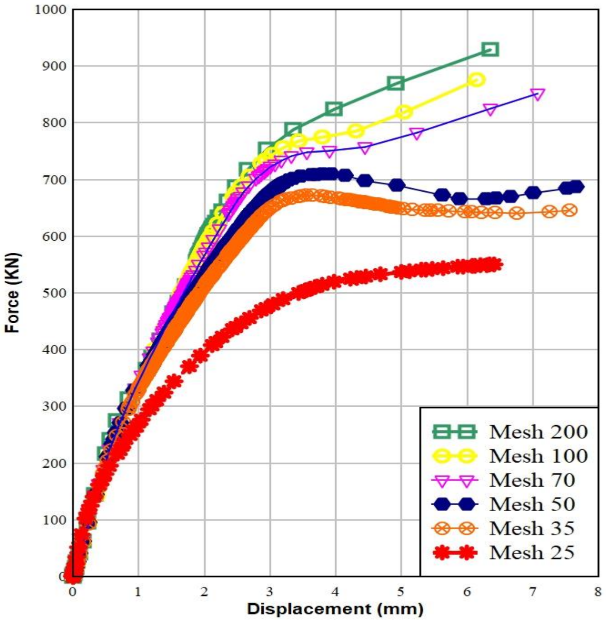


Figure 2. The Mesh Sensitivity Curve

3. The Validation Model Results

For N. Zhang’s experimental model, the load-displacement curve and the ultimate load capacity were conducted by an acquisition system. The load-deflection curve was used to validate this FEA model. Load-deflection curve is considered as the best way to measure the behaviour of reinforced concrete structures [12]. The deflection was measured under the loading point as the experimental test. As shown in Figure 3, the ultimate load was observed experimentally to be 515 KN with corresponding deflection of 5 mm. While, in the FEA model the ultimate load was 530 KN which is 3% higher than the experimental results. The maximum deflection seems to be the same.

Generally, this validation gives as a very good result which enable us to use this trusted model, conducted in ABAQUS software, far away in the later parametric study. There is a noticeable variance in the initial stiffness of the two models. However, this variation was investigated by many researchers. They concluded that the concrete damage plasticity model is significantly used to describe the behaviour of concrete but does not take the effect of the damage due to crack propagation into consideration [8].

4. Parametric Analysis

A new embedded truss model was created in this study to simulate HSTRCB. The traditional reinforcing bars were replaced completely with embedded angle-truss system. The lower steel reinforcement bars were replaced by two steel angles. The upper steel reinforcement bars were replaced by two steel angles. While the stirrups were replaced by thin steel plates. For flexural behavior investigation, five HSTRCB with dimensions of, 250 x 400 x 4000 mm were tested using ABAQUS software under 4-point loading test. A conventional reinforced concrete beam (RB) was modeled and tested to be used as a control beam to compare the behavior of the other five HSTRCB. The cross section of the control beam and HSTRCB are shown in Figure 4. All HSTRCB were reinforced with, two steel angles 50 x 50 x 5 as a lower reinforcement. Two steel angles 35 x 35 x 5 mm were used as upper reinforcement. The stirrups were replaced by thin plates 30 x 4 x 320 mm. the reinforcing configuration details of the tested beams and their FEA models are shown in Table 1 and Table 2.

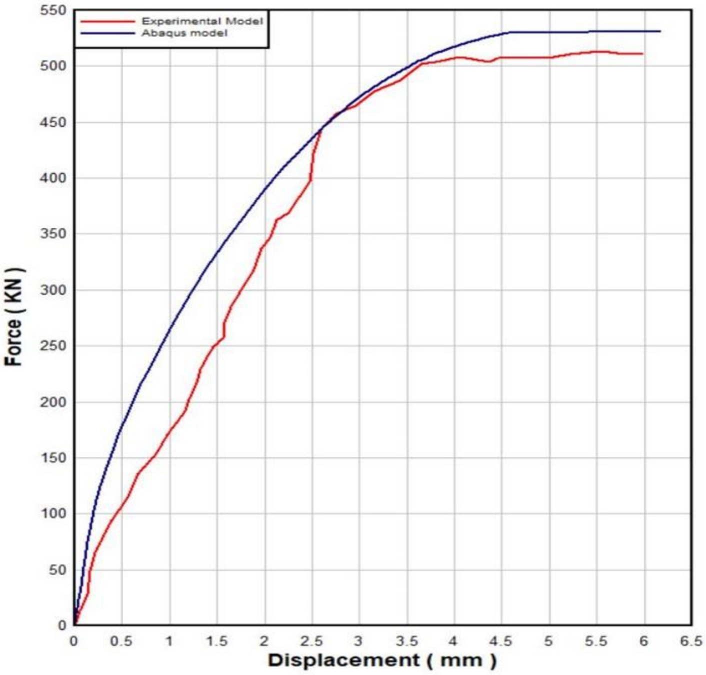
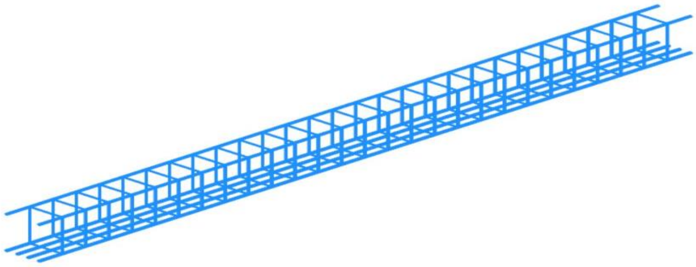
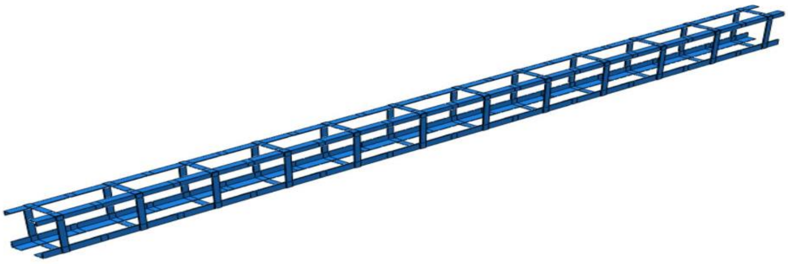
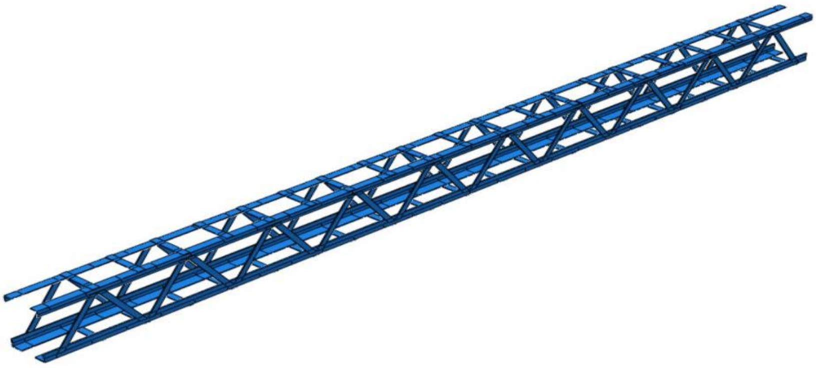
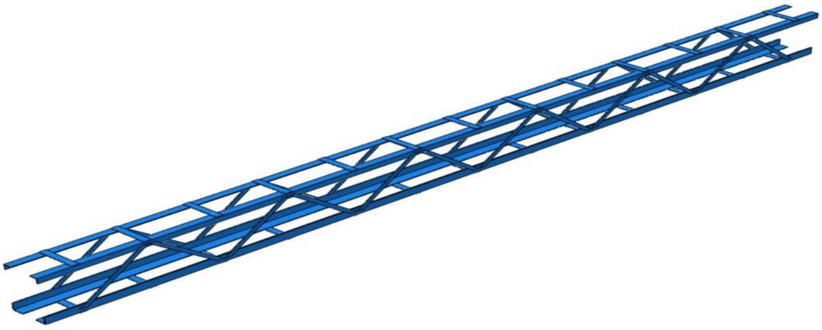


Figure 3. load-displacement curves of the N.Zhang’s model and validation model

Table 1 Reinforcing details of the tested beams and their FEA modelling.

The Specimen Name	The Reinforcing Simulations in ABAQUS
RB	
TCB1	
TCB2	
TCB3	

The Concrete Damage Plasticity (CDP) parameters were taken as the following: the dilation angle 31˚, the rate of the approaching of the flow potential to asymptote 0.1, the ratio between the compressive yield stress in case of equi-biaxial test and that of the the initial uniaxial test was taken as its default value 1.16. The constant stress ratio is 0.67. The viscosity is 0.001. In order to define the concrete compression damage and tension concrete damage, all the values of the yield stress and the corresponding inelastic strain were taken from the study carried by Milad Hafezo et el [13]. They have tested beams with different compressive strengths 20, 30, 40, and 50 MPa. named as B20, B30, B40, B50 respectively, as shown in Table 2. The bond between the steel truss system and concrete is assumed to be perfect bond where the debonding failure might happen due to the smooth surface of angles and low compressive strength of concrete is negligible.

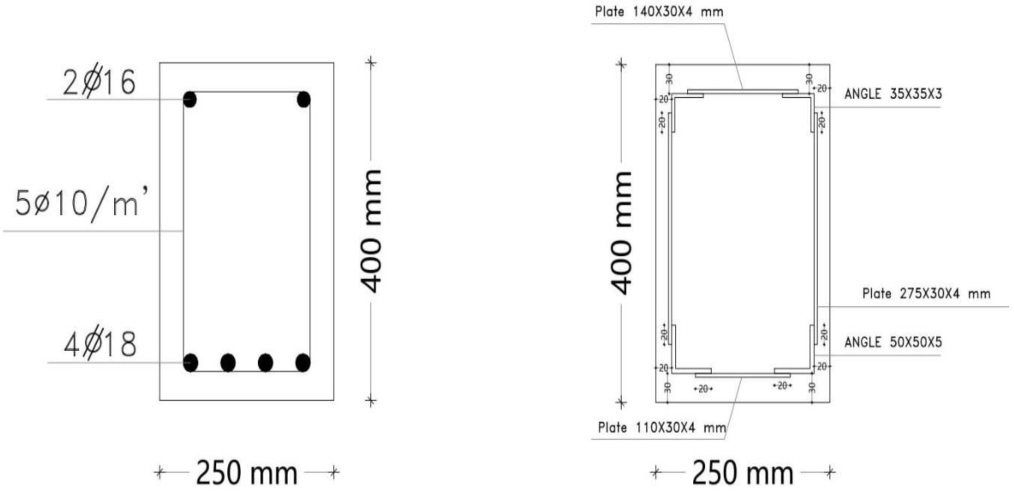


Figure 4. The cross sections of RB and trussed composite beams (all the dimensions in mm)

Table 2. The details of the tested beams (all the dimensions in mm)

Specimen Name	Upper Reinforcement	Bottom Reinforcement	Stirrups	Inclination Angle	Fcu (As in [13])
RB	2Ø16	4Ø18	5Ø8/m	90˚	B30
TCB1 (90˚ inclination)	2L 35x35x5	2L 50x50x5	Pl 30x4 Vertically placed with spaces 280 mm	90˚	B30
TCB2 (60˚ inclination)	2L 35x35x5	2L 50x50x5	Pl 30x4	60˚	B30
TCB3 (45˚ inclination)	2L 35x35x5	2L 50x50x5	Pl 30x4	45˚	B30
TCB4	2L 35x35x5	2L 50x50x5	Pl 30x4	45˚	B20
TCB5	2L 35x35x5	2L 50x50x5	Pl 30x4	45˚	B40

5. Results and Discussions

5.1. Changing the Inclination Angle:

Figure 5 shows the load-displacement curves of the tested beams (RB, TCB1, TCB2, and TCB3). All the beams almost have the same first crack load while the maximum load reached by the standard reinforced beam (RB) was 220 KN. The corresponding deflection was 14 mm, for RB, while that for the HSTRCB was 255 KN and the corresponding displacement was 20 mm. The beams with inclined stirrups (TCB2 and TCB3) showed a better flexural behavior in comparison with the standard reinforced beam with improvement of 12%. All HSTRCB nearly have the same initial stiffness. Moreover, their behavior in the post-peak region shows that the truss system still carries the load although the concrete starts to crush.

5.2. Changing the Compressive Strength of Concrete:

Figure 6 illustrates the effect of changing the compressive strength of concrete on the flexural behavior of the beams. The trussed composite beam with inclined plates with 45˚ was chosen to study this parameter as this reinforced technique showed the best results in the previous section. The FEA models showed that the more the increase in the compressive strength of concrete the more the improvement in the behavior of trussed beams. The capacity of the beams B40 improved by 16% relative to B20.

Figure 7 shows, the crack propagation diagrams of TCB4 and RB. All the trussed specimens with inclined stirrups almost showed the same behaviour in crack propagation so only one specimen (TCB4) was chosen to study this parameter and compared it with the standard reinforced beam. The results showed that the cracks distribution range increased due to the load distribution over wide range in TCB4. This could be concluded as, the action of the inclined stirrups which gives better flexural behavior compared to the control beam (RB).

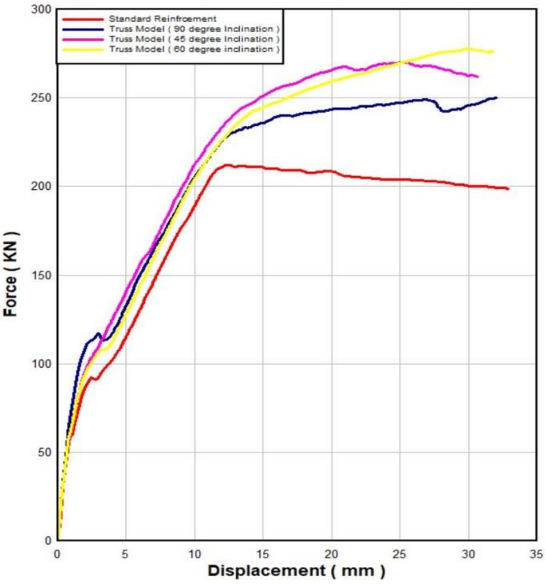


Figure 5. load-displacement curves of RB, TCB1, TCB2 and TCB3

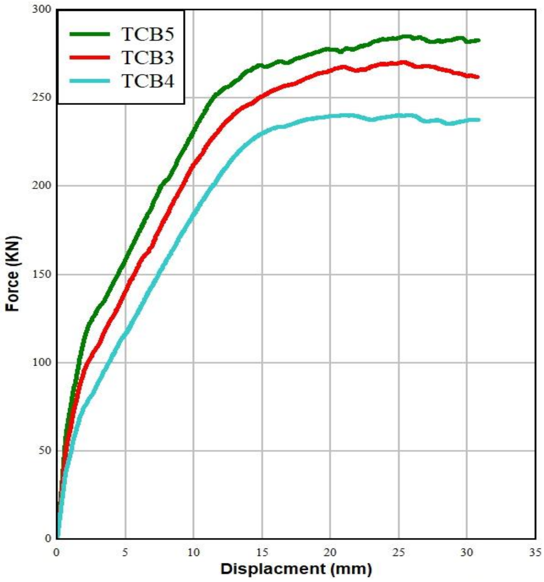
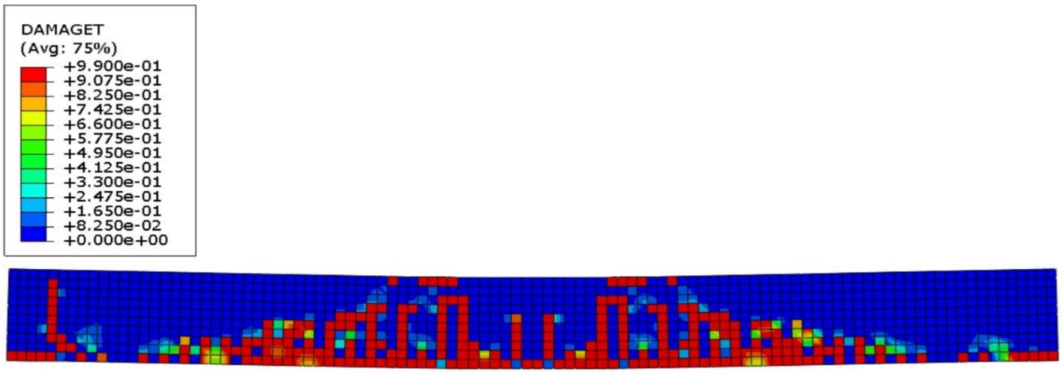
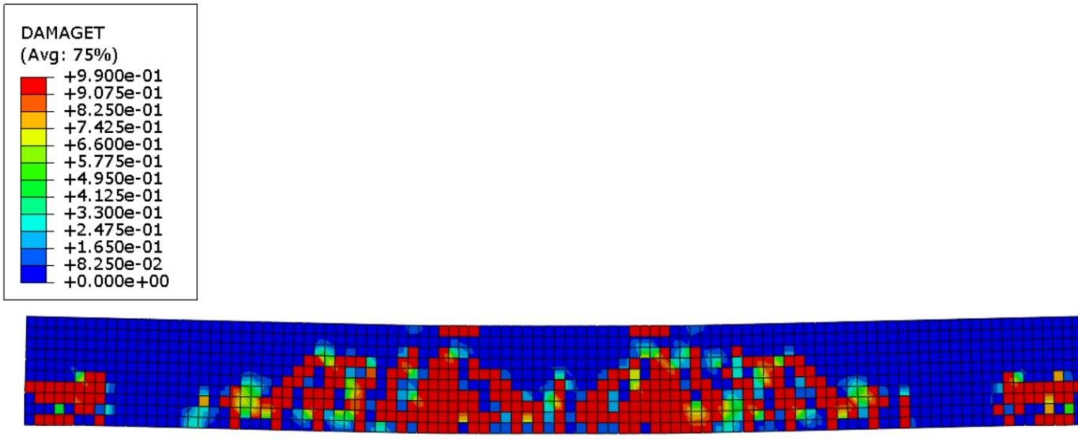


Figure 6. load-displacement curves of TCB3, TCB4 and TCB5



(a)



(b)

Figure 7. The crack propagation diagram of: (a) RB and (b) TCB4

6. Conclusions

A parametric study was conducted to optimize several parameters using a reliable FE model. Five composite trussed-beam specimens and control beam were modelled to investigate the ultimate flexural capacity. Load-deflection curve was utilized to measure the flexural capacity of the beams. Based on the results obtained from the study, the following results could be concluded:

- The trussed beams with inclined stirrups have better flexural behavior compared with the standard reinforced beam. The improvement percentage was 11%.
- All trussed beams showed a very noticeable ductile behavior in the plastic region (strain hardening) below the ultimate load. The (strain softening) load decaying did not happen in the range of study.
- Regardless of the bond strength between the steel parts and concrete, all failures happened to the beams was flexure failure. The behavior of trussed beams showed a considerable improvement by increasing the compressive strength of concrete.

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