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Strength study of stiffeners on castellated beam for circular and hexagonal opening using ANSYS

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Abstract
With the development of design optimization and advancement in construction, castellated beams gain its advantage due to its increased depth of section without any additional weight. The limitation of castellated beam is the stress concentration around the opening which reduces the stability of the beam and shear carrying capacity of the beam is also reduced. In this paper, steel I section ISMB 150 is selected and castellated beams are fabricated for circular and hexagonal opening such that depth of the beam is 1.5 times greater than the original depth. The beam is analysed using Finite Element Analysis (ANSYS).Two point loads is applied and stress distribution is studied. To reduce the stress concentration and to improve the shear carrying capacity stiffeners are introduced. Two types of stiffeners, diagonal & vertical stiffeners are introduced on the castellated beam. Vertical stiffeners on the solid portion of castellated beam and diagonal stiffeners on the hole openings.

Keywords: castellated beam, hexagonal, circular opening, diagonal, vertical stiffeners, stress distribution

1. Introduction
Steel structure building are becoming more and more popular due to their many advantages such as the better satisfaction with the flexible architectural, durability, strength, design, low inclusive cost and environmental protect as steel is manufacture to precise and uniform shapes [1].

1.1 General
The web of the section is cut by flame along the horizontal x-x axis along a “Zigzag” pattern as shown in the Fig. 1. The two halves are then welded together to produce a beam of greater depth with hexagonal opening in the web. The resulting beam has a larger section modulus and greater bending rigidity than the original section without an increase in weight [2]. However, the presence of the holes in the we will change the structural behavior of the beam from that of plain webbed beams. Experimental tests on castellated beams have shown that beam slenderness, castellation parameters and the loading type are the main parameters which dictate the strength and modes of failure of these beams.

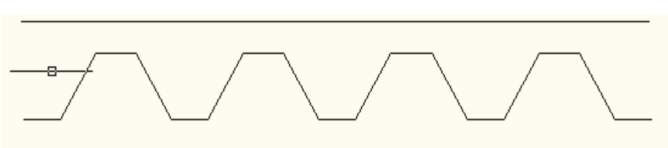
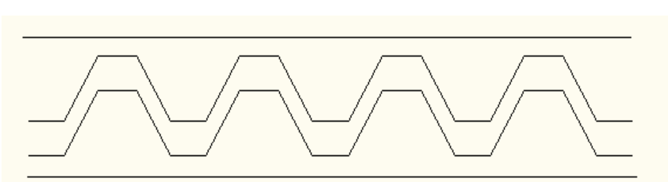


Fig 1: x-x Axis along a “Zigzag” Pattern



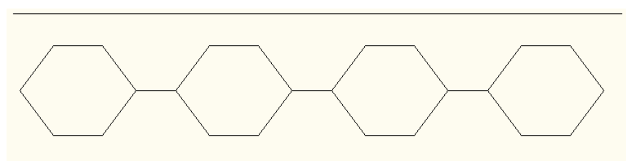


Fig 2: Hexagonal Opening

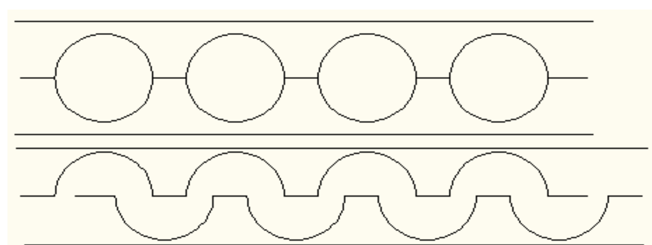


Fig 3: Circular Opening

1.2 Castellated Beam
Castellated beams are fabricated from wide flange I-beam. The web of the section is made cut along horizontal x-x axis. The two halves are then welded together to produce a beam of greater depth without any increase in the weight. Here the hexagonal opening is shown in fig 2. The resulting beam has greater bending rigidity and larger section modulus. The cutting angle varies from 45^o to 70^o and the commonly used sections are 45^o and 60^o. The circular opening is shown in fig 3.

2. Behaviour of Castellated Beams
There are six different modes of failures have been reported till date in castellated beams**.**

2.1 Vierendeel or Shear Mechanism
Vierendeel or Shear Mechanism occurs due to excessive

deformation across one of the openings in the web and formation of hinges in the corners of the castellation. This mode of failure is associated with high shear force acting on the beam. Formation of plastic hinges at the reentrant corners of the holes deforms the tee section above the openings to a parallelogram shape. When a castellated beam is subjected to shear, the tee sections above and below the openings must carry the applied shear, as well as the primary and secondary moments.

2.2 Flexural Mechanism

Under pure bending, provided the section is compact. The tee sections above and below the openings yield in tension and compression until they become fully plastic [4]. They concluded that yielding in the tee sections above and below the openings of a castellated beam was similar to that of a solid beam under pure bending forces. Thus, the maximum in-plane carrying capacity of a castellated beam under pure moment loading was determined to be Mp= ZxF where 'Z' is the full section plastic modulus taken through the vertical centerline of a hole.

2.3 Lateral - Torsional Buckling

Lateral Torsional Buckling is caused by large shear at the welded joints. As in solid web beams, out of plane movement of the beam without any web distortions describes this mode of failure.

2.4 Rupture of Welded Joints

Rupture of welded joints in the web arises due to excessive horizontal shear at the welded joint in the web. The mid depth weld joint of the web post between two openings may rupture when horizontal shear stresses exceed the yield strength of the welded joint. As mentioned in the formation of a Vierendeel Mechanism is likely to occur in beams with long horizontal hole lengths and hence long welds. On the other hand, short weld lengths are prone to cause failure of the welded joints as the horizontal yield stress is exceeded [3, 6].

2.5 Web Post Buckling

Web buckling is caused by heavy loading and short span of the beam. This may be avoided at a support by filling the first castellation by welding a plate in the hole. The horizontal shear force in the web-post is associated with double curvature bending over the height of the post. Many analytical studies on web post buckling have also been reported to predict the web-post buckling load due to shearing force. Based on finite difference approximation for an ideally elastic-plastic-hardening material produced some graphical design approximations for a wide range of beam and hole geometries some correlations between experimental and non-linear finite analysis estimations were found in the works of Redwood (1996).

2.6 Web Post Buckling due to Compression

A concentrated load or a reaction point applied directly over a web-post causes this failure mode. This mode was reported in the experiments conducted by Toprac and Cook (1959). Husain and Speirs (1973). Buckling of the web post under large compression forces is not accompanied by twisting of the post. as it would be under shearing force. Such a failure mode could be prevented if adequate web reinforcing stiffeners are provided. A strut approach was proposed in the works of (Dougherty 1993) which suggests that standard column equations could be used to determine the strength of the web post located at a load or a reaction point.

3. Advantage and Limitation of Castellated Beams

They have cheap labour cost. Interms of structural performance, the operation of splitting and expanding of rolled sections help to increase the section modulus of the beams. Since the load carrying capacity of the beam is also increased. It reduce the deflection of the building. No need of plate girder in the castellated beam [5].

3.1 Limitations

Shear concentrations occurs near the perforations and the shear carrying capacity is reduced by making perforations near the neutral axis where the stress are small making the cut in zig-zag way.

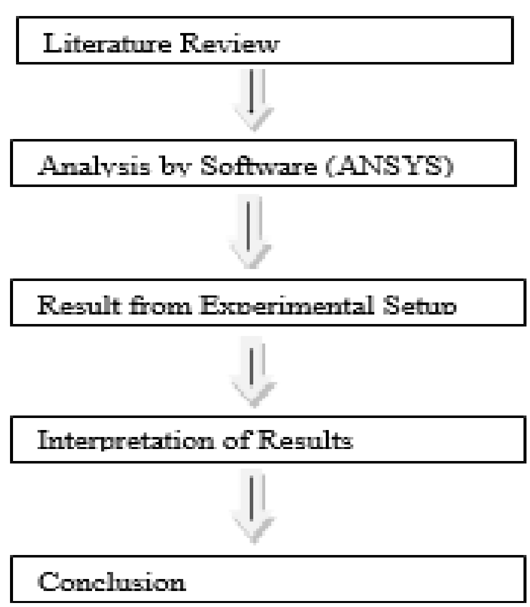
3.2 Objective of Study

- Stiffners are introduced along the web opening in to minimize the deflection and control shear failure.
- To study the behaviour of Load vs Deflection
- To determine the limited number of holes to be provided in a section
- To reduce the shear failure in web openings by providing stiffners
- To study the shear failure of the castellated sections
- To study the experimental and analytical investigation of static loading

3.3 Scope of Work

The scope of this project is focussed on the investigation and behaviour of the Shear strength of the castellated beam through an extensive finite element study (ANSYS).

4. Methodology



5. Literature Review

These are some of the conclusions from various literature reviews about castellated beam,

a. When stiffeners are provided vertically along with diagonal stiffeners. Shear failures is more near the hole than the web, hence shear stiffeners are provided on the opening of the web long the shear zone. Hence concluded that shear strength of the beam is improved by introducing shear stiffeners along shear zone
b. The depth of opening increases in Vierendeel effects is prominently observed at the hole corners, so by taking corrective measures (i.e corners should be rounded, provision of reinforcement) will improve the performance of beam.
c. The area of web opening is more rectangular opening shows very poor performance at predicted loads. It is found that as the web post width decreases the corresponding predicted buckling load and yielding mechanism load increase due to the decrease in area of corresponding web openings. As the web thickness increases, the corresponding predicted buckling load and yielding mechanism load increases.
d. The size of the beam increases the deflection of beam is decreases. As the web opening move towards the centre of beam, deflection goes on decreasing. Stress is decreasing as section of beam is increasing. Stress is least for circular web opening and more for square web opening.

6. Numerical Study

6.1 General

Several theoretical approaches are considered to analyze the yielding and buckling failure modes of castellated beams. Elastic finite element analysis is used to predict the ultimate load. Finite element model generation is done using ANSYS finite element package software is described in this chapter [12].

6.2 Investigation of Castellated Beam

The numerical models were created using ANSYS software. The numerical modeling involves linear and non-linear analysis.

- Select the angle of cut to be 45° for a good design
- The depth of the stem of the T section at the minimum cross section should not be less than ¼ of the original beam section. Calculate the moment of resistance of the castellated section which is the product of the resultant tensile or compressive force and the distance between centroids of T sections [7, 8].

MR = A σat d

The spacing of the castellated beam should not exceed the spacing determined by the equation

Where,

S = P'/WL

S = center to center distance between castellated beams

P'= Net load carrying capacity in N

W= Design load in N/m^2

L = Span of the beam in m

- The maximum deflection of the T- section is at the mid span and is due to the net load carrying capacity and local effects.

$\delta = \delta 1 + \delta 2 < L/325$

Where

δ1 – Deflect ion due to net load carrying capacity

δ2 - Deflection due to local effects

6.3 Section Identification

Table 1: Specimen details in IC 225 and IC 300

Specimn Detail	WDS 225	WVS 225
Length (m)	3.5	3.5
Thickness of flange tf (mm)	7.5	7.5
Thickness of the web tw (m	5	5
Breath of the web bw (mm)	80	80
Height of the web opening HW (mm)	150	150
Length of stiffener (mm)	200	200
Width of stiffener (mm)	20	20
Thickness of Stiffener (mm)	5	5

6.4 Assumptions Made In the Analysis

The following assumption are adopted for linear and Non-linear analysis Density of steel, young's modulus of steel, poisson ratio, yield strength and plastic strain are the basic parameters of the section. All dimensions are in meter.

1. Yield strength (fy) = 2.5 x108 N/m2
2. Young's modulus = 2 x1011 N/m2
3. Poisson's ratio = 0.3
4. Density of Steel = 7830 kg/m3
5. Plastic Strain = 0

7. Finite Element Analysis

In this paper, a three dimensional (3D) finite element model is developed using ANYSIS-14 for IC 225 and IC 300. Various finite element models and von misesstresses are developed. Stress concentration of the beam is studied. Stress concentration is more near the opening leading to shear failure [9, 10, 11].

Hence the webs are stiffened by providing stiffeners on either side of the beam along the shear zone to reduce the stress concentration and to reduce the shear deformation. Stiffeners are provided on opening of the web and also on the solid portion of the web. In order to study the effect of stiffeners along shear zone the following three cases are considered Case (I) With Diagonal Stiffeners (WDS) on the web opening along the shear zone. Case (II) with vertical Stiffeners (WVS) on the solid web along the shear zone.

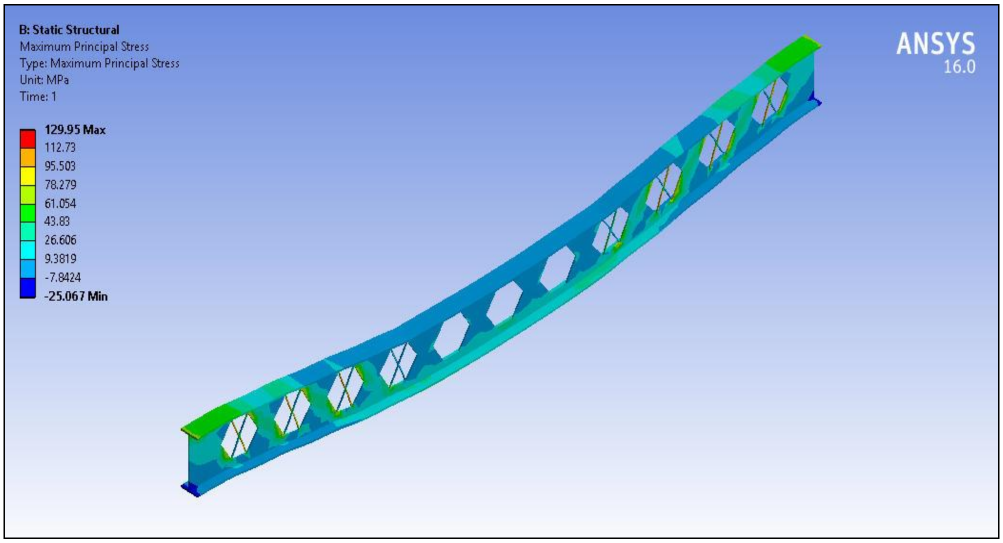


Fig 4: WDS 225 Deflection (mm)

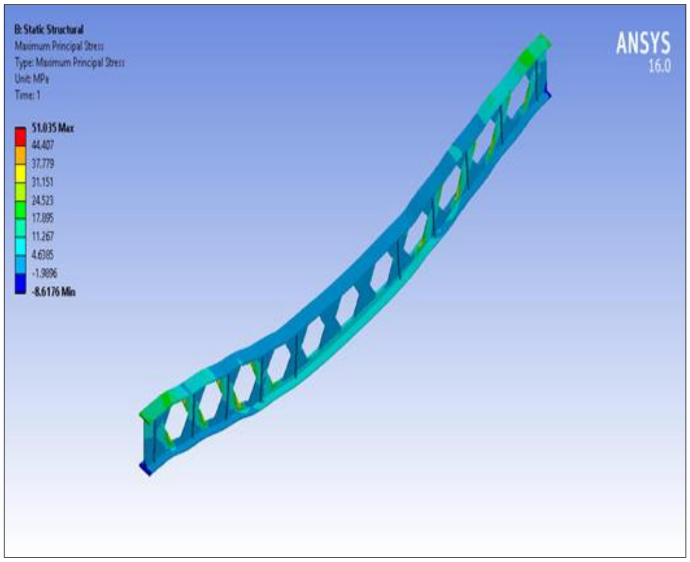


Fig 5: WVS 225 Deflection (mm)

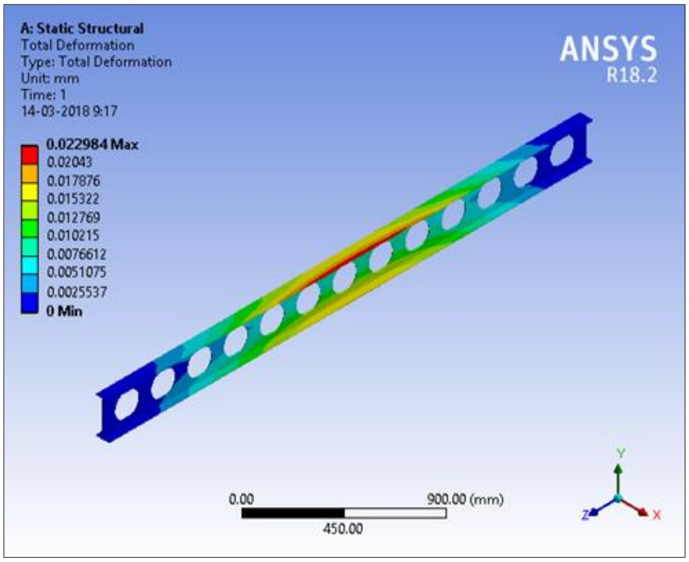


Fig 6: 225 Castellated Beam (Circular Opening)

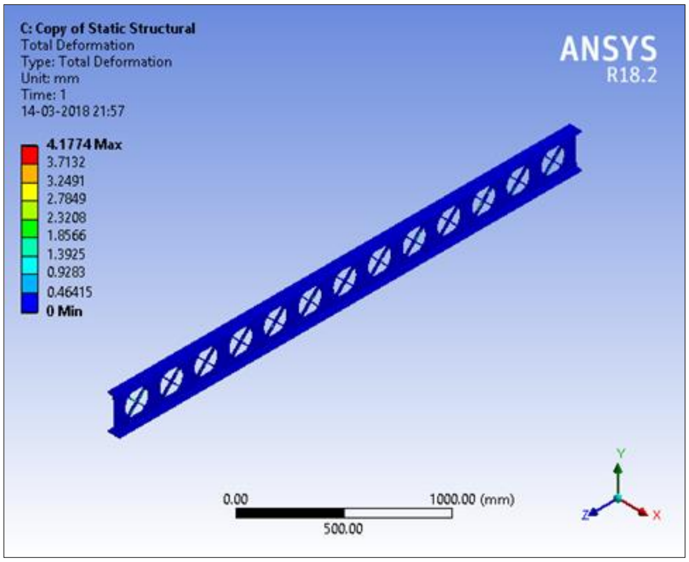


Fig 7: WDS 225 Deflection (mm)

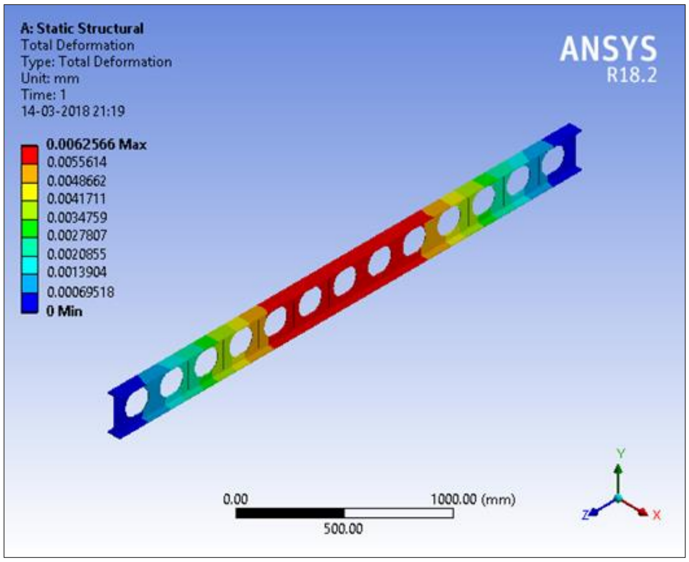


Fig 8: WDS 300 Deflection (mm)

8. Results and Discussion

Figure 14 represents the load Vs deflection comparison of castellated beam with diagonal stiffeners for hexagonal and circular opening. As load increases deflection of castellated beam of diagonal stiffeners for circular opening increases when compared to hexagonal opening. Diagonal stiffeners reduces the stress concentration around the hole corners and transfers the load through the opening.

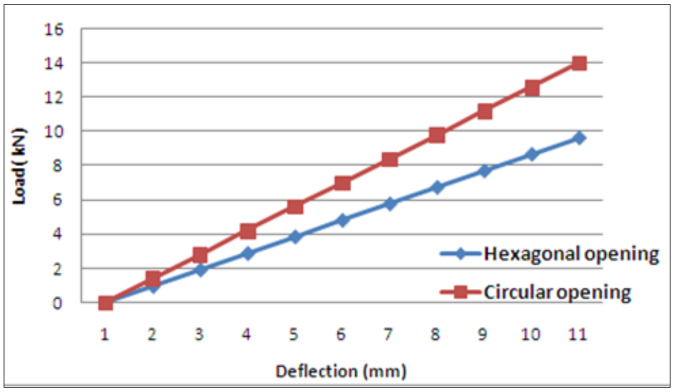


Fig 9: Load Vs Deflection Comparison of CB with Diagonal Stiffeners (Hexagonal & Circular opening)

Figure 15 represents the load Vs deflection comparison of castellated beam with vertical stiffeners for hexagonal and circular opening. When stiffeners are provided vertically deflection of castellated beam is reduced. But when compared to circular opening hexagonal opening is having lesser deflection.

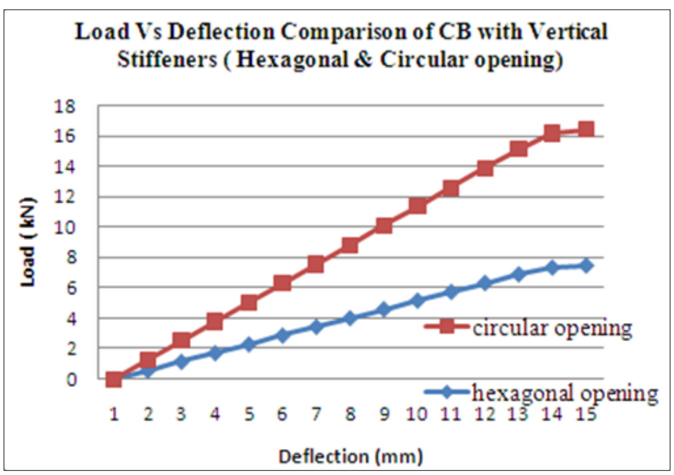


Fig 10: Load Vs Deflection Comparison of CB with Vertical Stiffeners (Hexagonal & Circular opening)

Table 2: Ultimate load comparison of hexagonal & circular opening for diagonal & vertical stiffeners.

S. No	Load (KN)	Ultimate load (KN)	
		Diagonal Stiffeners	
		Hexagonal opening	**Circular opening**
1.	110	10.59	15.4
		Vertical Stiffeners	
		Hexagonal opening	Circular opening
1.	140	7.46	8.92

Table 2 gives the ultimate value of hexagonal & circular opening for diagonal & vertical stiffeners. Diagonal stiffeners reduces the stress concentration. Vertical stiffeners increases the load carrying capacity and stability of the beam.

9. Numerical Modelling

The numerical models were created using ANSYS software, which was also used to evaluate the ultimate load of the sections. The numerical modelling involves linear and non-linear analysis. In the linear analysis, the sections were considered to have a perfect geometry in order to determine the probable buckling behaviour. In non-linear analysis, both geometric and material non-linearities were incorporated and performed by Modified Risk method (ANSYS) to examine the ultimate load and failure modes of the beam [7, 8].

10. Conclusion

1. It can be concluded that castellated beams are well accepted for industrial buildings, power plant and multistory structures, were generally loads are less and spans are more with its economy and satisfying serviceability criteria.
2. As the size of the beam increases the deflection of the beam is reduced deflection of ISMB 225 is more than ISMB 300.
3. As the web thickness tw of the section increases, the corresponding predicted ultimate load and yielding mechanism load also increases.
4. It was observed that Deflection without stiffeners is 13.32 mm, when stiffeners are provided diagonally on the web opening along the shear zone deflection is reduced to 11.4mm.
5. Energy absorption is better in providing vertical stiffeners in IC 225 section the energy absorption is 840joule and IC 300section the energy absorption is 1140 joule. Because of the introduction of stiffeners the energy absorption of the section is increased to 0.4%
6. From the above six cases it is predicted that, beam with varying web thickness and by providing diagonal stiffeners the deflection is controlled.
7. It is concluded that shear failure is more near the holes than the solid web, hence shear stiffeners provided on the opening of the web is effective than the solid portion.
8. Deflection can further be reduced by providing vertical stiffeners along with diagonal stiffeners in the shear zone of the web opening.
9. Therefore, castellated section with stiffeners hold good for aesthetic purpose, long span construction and cost effective *purpose.*

11. Courtesy

I would like to express my appreciation and sincere gratitude to my research guide B.ANU PRIYA ASSISTANT PROFESSOR, in Arasu Engineering College at Kumbakonam for her constant guidance throughout this research
Project. In this thesis the section used are IC 225 and IC 300 the section details, section properties, experimental data's and experimental photographs have been taken from B. Anu Priya.

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