A Study on Strength Characteristics of Steel-Boron Composites as Reinforcement Bars in Reinforced concrete Beam.

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Abstract: Metal matrix composites are the most widely used materials in automotive, aerospace, defense industries etc. The engineering properties of metal matrix composites [MMC] are well known. By relying on MMC’S, civil engineering field has lot of benefits. MMC’S are not well-versed in civil engineering discipline, due to lack of awareness and cost complexes. This paper deals with the study of strength characteristics of steel-boron fiber composite as reinforced bars in concrete beam. For this, steel-boron reinforcement was modelled by assembling the boron fibres [reinforcement] in steel bars [matrix], using ABAQUS software further this steel boron bars were assembled in concrete beam and analysed under required support and loading conditions. From the results it is observed that the strain in conventional steel beam is mor than in MMC reinforced beam, therefore, tensile strain capacity of beam increased by increasing the boron fibres in steel reinforcement.

Keywords: Metal matrix composites, Reinforcement, Strength characteristics, ABAQUS, tensile strain capacity.

1. Introduction:

There are various weight-percentage alternatives for cement and aggregates in concrete, but steel cannot be totally replaced in the case of reinforcement [1]. However, we can incorporate reinforcing material into steel to improve its performance. While there is no single alternative to steel that has become the industry standard, materials such as engineered wood and metal composites are becoming more common in new construction projects [2]. This paper deals with the study of MMC bars as reinforcement in concrete beam. In commercial construction, composite materials such as boron fibres-and alternative metal alloys are gaining traction. Composites are often more durable than steel, and repairing damaged composite components is often less expensive and requires less heavy equipment. In this steel boron Metal Matrix Composite (MMC) are used as reinforcement bars. Metal Matrix Composite is a composite material made up of at least two basic materials, one of which is metal, metal or another material, such as ceramic or organic compounds, could be used as the other material. When compared to unreinforced alloys, Metal Matrix Composites have significantly improved features such as high strength, specific modulus, and superior water resistance. Traditional materials are limited in their ability to provide high strength, stiffness, hardness, and density. Metal Matrix Composites are the most promising materials for overcoming these drawbacks. A reinforcing material is dispersed into a metal matrix to make Metal Matrix Composites. To avoid a chemical reaction with the matrix, the surface of the reinforcing material might be coated. The Matrix is a continuous monolithic material that contains the reinforcement. The Matrix holds the fibres together and is commonly made of a lighter metal like as aluminium, magnesium, or titanium. The matrix evenly distributes the loads over all fibres, ensuring that all fibres are subjected to the same amount of
stress. Improves a component's impact and fracture resistance while also carrying inter laminar shear. The substance incorporated in the matrix is called reinforcement. It improves wear resistance, friction coefficient, thermal conductivity, and other qualities. There are two types of reinforcement: continuous and discontinuous. Low density, thermal stability, high young's modulus, high compression and tensile strength are all desirable features in reinforcement. Process capability and economic efficiency are both important. Buildings, bridges, and pilings are all examples of MMC applications in civil engineering. MMCs are also suitable for usage as power transmission towers and railway tracks. MMCs are used in a variety of industries, including aerospace, automotive, electronics, and defence [1]. The wear and friction properties of aluminium matrix composites reinforced with short steel fibres were studied. The sliding wear resistance and coefficient of friction were determined using a pin on disc type device. The percentage of fibres used and the coating applied to the fibres influence wear resistance. The best wear resistance comes from a copper coating on steel fibres [2]. The wear rate of Al6061 when reinforced with hard ceramic alumina and soft solid molybdenum is investigated in this paper. Stir casting is used to make it. Enhancement in wear and friction resistance of alumina and molybdenum di sulphide particles [3]. Vickers hardness, wear behaviour, and wear data for pure Al and Al-Al2O3-TiO2 hybrid metal matrix composites are investigated in this study. The stir casting method was used to make it. Vickers hardness rises as the weight fraction of reinforcement rises [4]. The addition of reinforcements to aluminium matrix in various quantities, such as graphite, fly ash, silicon carbide, and so on, is the subject of this study. Each material has its own set of characteristics that complement the base alloy's. Graphite, fly ash, and alumina are examples of reinforcements that have higher tensile strength than silicon. Fly ash particles are the most effective for increasing compressive strength [5]. Aluminium metal matrix composites, as well as their manufacturing procedures and increased properties, are discussed in this paper. Different reinforcement combinations and their effects on performance were discussed. The AMC reinforced with two synthetic ceramics has strong mechanical and tribological qualities, but it still needs to be tested for corrosion [6-11]. Dry sliding wear behaviour of SiC reinforced metal matrix composites with a volume of 10-30% was examined in this study. Vacuum infiltration was used to create them. As the sliding distance and force rise, the wear rate of composites increases. The wear resistance improves as the volume of reinforcement grows.

The comparative analytical research involved in the determination of tensile strain capacity of beams with conventional steel reinforcement and MMC reinforcement with similar geometry, loading and support conditions is studied in this article.

2. Materials:

Boron fibers are made as monofilaments (single filaments) by chemical vapor depositing boron onto a tungsten wire or a carbon filament, with the latter being the most common. In comparison to most other reinforcements, they have rather enormous diameters (100–140 m). They are highly brittle and vulnerable to damage on the surface. Boron fibers, which are primarily employed in metal matrix composites, deteriorate when they come into touch with aluminum or titanium matrices at the processing temperatures (over 500°C). Chemical vapour deposition is utilized to coat the fiber surface with a 5 m thick layer of silicon carbide, SiC (such fibers are termed Borsic), or boron carbide, B4C, to prevent deterioration. Boron fibers were created to make composite materials more rigid. Boron fibers have a rare combination of compressive strength, young's modulus, and diameter.
2.1 Beam details:

The beam configuration for steel reinforcement and steel-boron fiber metal matrix composite reinforcement is presented in Table 1.

| Contents              | Steel reinforced beam | MMC reinforced beam |
|-----------------------|-----------------------|---------------------|
| **Length**            | 2 Meters              | 2 Meter             |
| **Width**             | 0.25 Meters           | 0.25 Meter          |
| **Height**            | 0.35 Meters           | 0.35 Meter          |
| **Material**          | Concrete              | Concrete            |
| **Type of reinforcement** | Steel             | Steel-Boron fiber MMC |
| **Grade of Steel**    | Fe415                 | Fe415               |
| **Grade of concrete** | M25                   | M25                 |
| **Properties of concrete** | E = 26000, μ = 0.25 | E = 26000, μ = 0.25 |
| **Properties of steel** | E = 200000, μ = 0.3  | E = 200000, μ = 0.3  |
| **Properties of boron** | E = 450000, μ = 0.13 | E = 450000, μ = 0.13 |

2.2 Calculations:

Volume fraction of boron fiber = volume of boron fiber / volume of steel bar =\(\pi d^2h/\pi D^2h\)

Where \(d\) = diameter of boron fiber = 2mm.

\(D\) = diameter of steel bar = 16mm.

Volume = \(\pi*2*2*1950 / \pi*16*16*1950 =0.015\).

For one boron fiber volume fraction [V.F] is 0.015.

Considering V.F s 0.25, 0.3, 0.4, 0.5.

Number of bars = area of steel bar * volume fraction/ area of boron fiber.

For V.F = 0.25.

Number of boron fibers = 201.06*0.25 / 3.14 =16.

For V.F = 0.3.

Number of boron fibers = 201.06*0.3/3.14 =20.

For V.F = 0.4.

Number of boron fibers = 201.06*0.4 / 3.14 = 26.

For V.F = 0.5.

Number of boron fibers = 201.06*0.5 / 3.14 = 33.
3. Analysis and Design of beam using ABAQUS Software:

ABAQUS is utilized in each and every industry around the world to power vital industry processes such as powertrain engineering, electronic drop simulation, composite wing structure performance, sealing design, and many more key activities that clients rely on a daily basis. It's a piece of software that allows you to model and analyze various components and assemblies (pre-processing) as well as visualize the results of a finite element analysis.

3.1 ABAQUS procedure:

The following are steps in ABAQUS:

1. Modelling of beam
2. Assigning properties.
3. Assembling the beam and reinforcement.
4. Specifying the step and increment.
5. Assigning the interactions between concrete and steel reinforcement.
6. Assigning loads and support conditions.
7. Meshing the elements.
8. Submission of job.

Figure 1a and 1b. represents the beam with dimensions 250mm width, 350 mm depth and 2m length for both the steel and MMC reinforced beams.

![Figure 1](image1)

Figure (1a). Steel reinforced beam. Figure (1b). MMC reinforced beam.

**Figure 1.** Beam model in ABAQUS

4. Results and discussion:

The beam modelling and analysis have been done using ABAQUS with 25mm downward displacement and the results are presented in this section.

From the ABAQUS output, it is observed that strain in MMC reinforced beam is less than that in steel reinforced beam and tensile strain capacity of MMC reinforced beam is more than the steel reinforced beam.
For 25mm downward displacement and at 15MPA maximum strain values for steel reinforced and different volume fractions of boron fibers are tabulated in Table 2.

**Table 2** Strain values of steel and MMC reinforced beams.

| Stress (15MPA) | Steel reinforced beam | MMC (V.F =0.25) | MMC (V.F =0.3) | MMC (V.F =0.4) | MMC (V.F =0.5) |
|---------------|----------------------|-----------------|----------------|----------------|----------------|
| S11E11(U)     | 0.0064               | 0.0032350       | 0.003070       | 0.0026586      | 0.0024676      |
| S22E22(U)     | 0.00125              | 0.0006415       | 0.000593       | 0.0005270      | 0.0002522      |
| S11E11(R.F)   | 0.0041               | 0.0001840       | 0.000166       | 0.0001506      | 0.0001490      |
| S22E22(R.F)   | 0.0036               | 0.0004187       | 0.000352       | 0.0003510      | 0.0000342      |

Where U = Displacement
R.F = Reaction forces
V.F = Volume fractions

**Figure 2.** stress strain curve in S11E11 direction from displacement data.

Figure 2 represents the variation of tensile strain capacity of steel reinforced and MMC reinforced (with different volume fractions) beam in x face x direction related to displacement. Here, conventional steel reinforced beam has more strain than MMC reinforced beam for the same stress and also increase in volume fraction (V.F) of boron fibers decreases the strain. This conventional steel reinforced beam has less tensile strain capacity when compared with MMC reinforced beam. Moreover, tensile strain capacity increases with increase in the volume fraction of boron fibers.
Figure 3. stress strain curve in S22E22 direction from displacement data.

Figure 3 represents the variation of tensile strain capacity of steel reinforced and MMC reinforced (with different volume fractions) beam in y face y direction related to displacement. Here, conventional steel reinforced beam has more strain than MMC reinforced beam for the same stress and also increase in volume fraction (V.F) of boron fibers decreases the strain. This conventional steel reinforced beam has conventional steel reinforced beam has less tensile strain capacity when compared with MMC reinforced beam. Moreover, tensile strain capacity increases with increase in the volume fraction of boron fibers.

Figure 4. stress strain curve in S11E11 direction from reaction forces.

Figure 4 represents the variation of tensile strain capacity of steel reinforced and MMC reinforced (with different volume fractions) beam in x face x direction related to reaction forces. Here, conventional steel reinforced beam has more strain than MMC reinforced beam for the same stress and also increase in volume fraction (V.F) of boron fibers decreases the strain. Therefore, conventional
steel reinforced beam has less tensile strain capacity when compared with MMC reinforced beam. Moreover, tensile strain capacity increases with increase in the volume fraction of boron fibers.

![Figure 5](image-url)

**Figure 5.** Stress strain curve in S22E22 direction from reaction forces.

Figure 5 represents the variation of tensile strain capacity of steel reinforced and MMC reinforced (with different volume fractions) beam in y face y direction related to reaction forces. Here, conventional steel reinforced beam has more strain than MMC reinforced beam for the same stress and also increase in volume fraction (V.F) of boron fibers decreases the strain. Therefore, conventional steel reinforced beam has less tensile strain capacity when compared with MMC reinforced beam. Moreover, tensile strain capacity increases with increase in the volume fraction of boron fibers.

**Strain distribution of tensile reinforcement:**

The maximum strain obtained in conventional steel reinforcement is 0.00009861 and in MMC reinforcement for different V.F ‘s of 0.25, 0.3, 0.4, 0.5 maximum strain obtained is 0.0003801, 0.0003517, 0.0002369, 0.0002335 respectively. Therefore, strain in conventional steel is more than strain in MMC reinforcement, also by increasing the V.F of boron fibers strain decreases.

5. **Conclusions:**

The following are the conclusions drawn from the present study

It is observed that for the same load and support conditions strain in steel reinforced beam is more than strain in MMC reinforced beam. Therefore, the conventional steel reinforced beam has less tensile strain capacity when compared with steel boron fibre (MMC) reinforced beam and when compared between the volume fractions of boron fibres of 0.25, 0.3, 0.4 and 0.5, maximum tensile strain capacity is attained at 0.5 volume fraction, which concludes that increasing the boron fibres increases tensile strain capacity of the concrete beam.

6. **Appendix**

1. MMC – Metal Matrix Composite.
2. V.F – Volume fraction.
3. E – Youngs Modulus.
4. \( \mu \) - Poisson’s ratio.
5. \( S_{11E11(U)} \) – Stress and logarithmic strain related to displacement in x face x direction.
6. \( S_{22E22(U)} \) – Stress and logarithmic strain related to displacement in y face y direction.
7. \( S_{11E11(R.F)} \) – Stress and logarithmic strain related to reaction forces in x face x direction.
8. \( S_{22E22(R.F)} \) – Stress and logarithmic strain related to reaction forces in y face y direction.
9. MMC – Metal matrix reinforcement.

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