Mechanical Behavior of Fiber Reinforced Composites

MECH 6333 - Materials Design and Manufacturing

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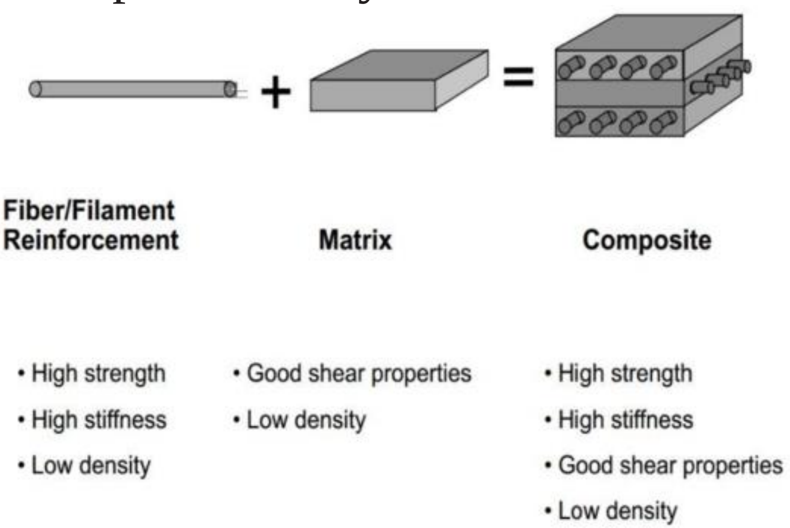
Introduction

- **<u>Composites – matrix & reinforcement</u>**

A *composite* is composed of two (or more) individual materials that are—metals, ceramics, and polymers. The design goal of a composite is to achieve a combination of properties that is not displayed by any single material and also to incorporate the best characteristics of each of the component materials. A large number of composite types are represented by different combinations of metals, ceramics, and polymers.

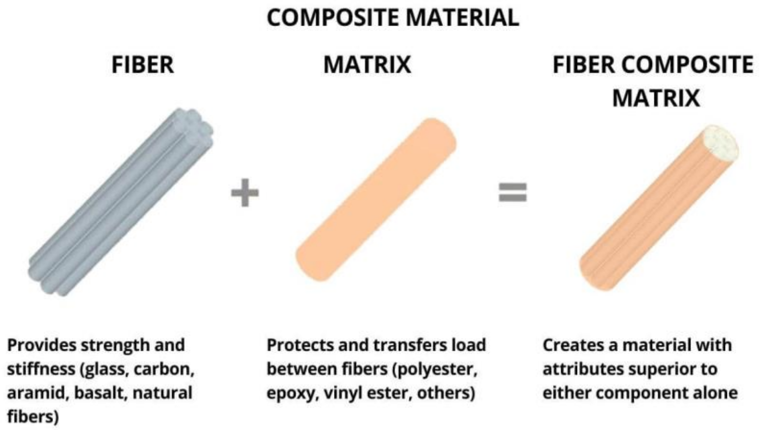


- **<u>Types of composites</u>**

Composites are usually classified by the type of reinforcements they use. These reinforcements are embedded into a matrix that holds it together. The reinforcements are used to strengthen the composites.

The four main categories based on reinforcements:

i. Particle-reinforced
ii. Fiber- reinforced
iii. Structural
iv. Nanocomposites



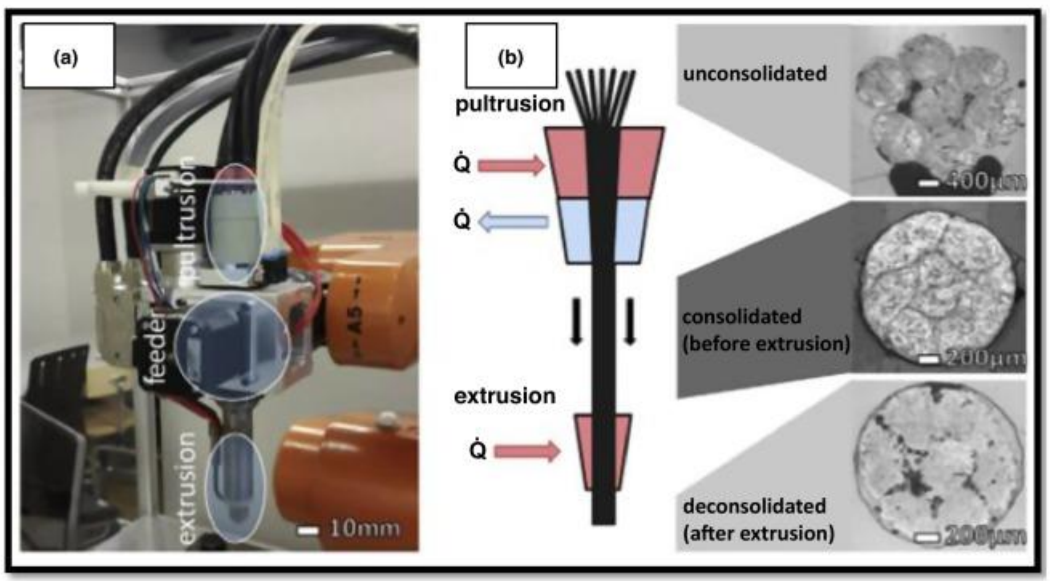
The four primary categories based on matrix:

i. Polymer matrix composites (PMCs)
ii. Metal matrix composites (MMCs)
iii. Ceramic matrix composites (CMCs)
iv. Carbon matrix composites (CAMCs).

- **FDM (Material Extrusion)**

i. CLF (Continuous Lattice Fabrication)

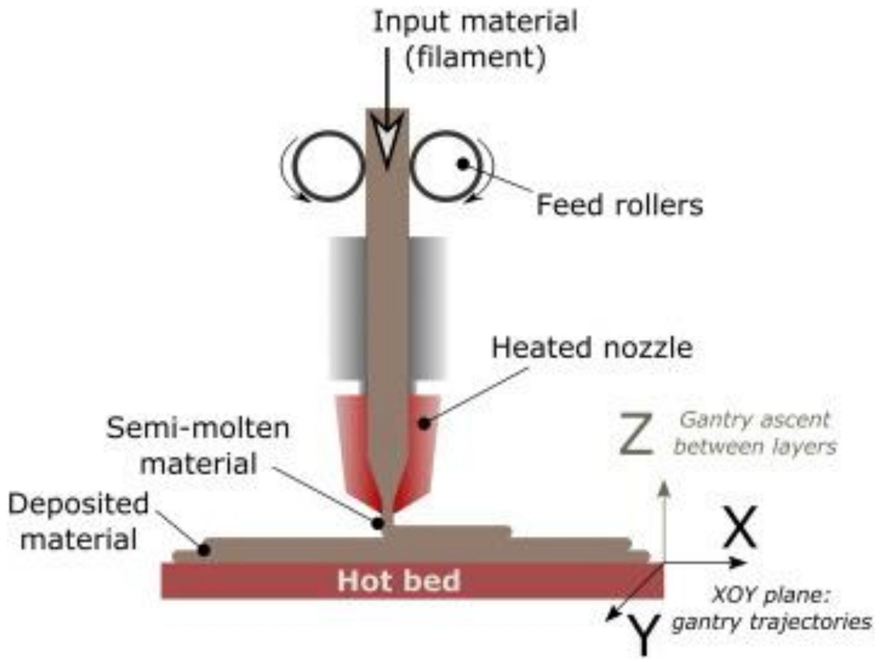
In this technique, the spatial extrusion principle is used for free-standing and self-supportive filaments without any supporting parts. The subsequent layers are directly deposited on base material or substrate.



Current Opinion in Chemical Engineering

ii. FFF (Fused Filament Fabrication)

The FFF process is material extrusion-based AM techniques, which mainly comprises the nozzle and moving platform. The material is heated at the nozzle, and it is deposited onto a moving platform.



Additive Manufacturing of Composites

- **SLA (Vat Photopolymerization)**

The reinforcement fiber is immersed in the UV-curable resin, and then it is allowed to cure at the printing base during the photo-polymerization.

- **GFRP**

Glass fiber reincforced polymer also known as glass fiber reinforced plastic is a composite material we get by weaving fiber E-glass and polyester material together. The woven material can be hardened with a thermosetting polymers such as epoxy, resin or thermoplastics.

Additive Manufacturing of Composites

- **Metal-Matrix Composites**

A metal matrix composite (MMC) is a composite material with fibers or particles dispersed in a metallic matrix, such as copper, aluminum, or steel. The secondary phase is typically a ceramic (such as alumina or silicon carbide) or another metal (such as steel).

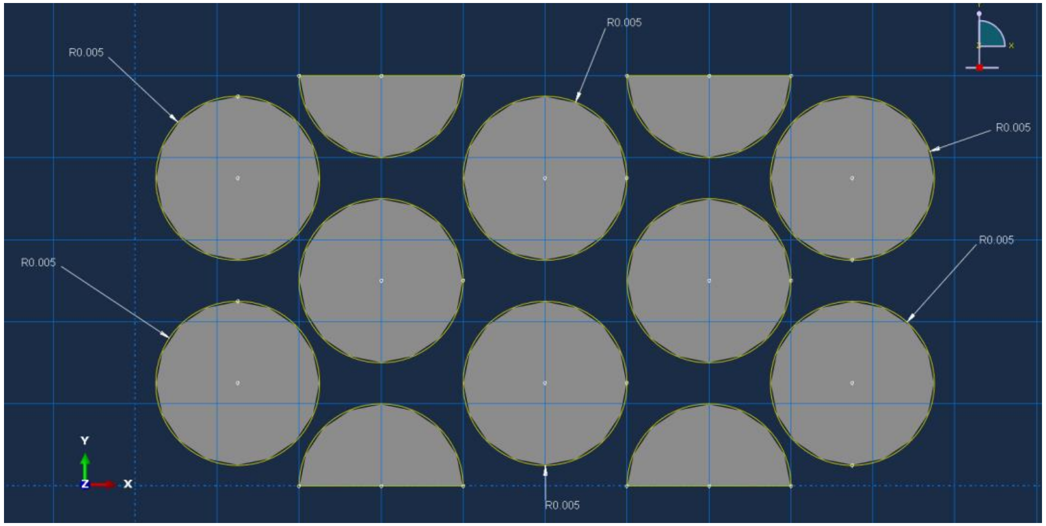
- **Advantages & Disadvantages over conventional fabrication methods**

The layer-by-layer fabrication process eliminates the expensive conventional molds during the fabrication process.

The AM processes has not entirely replaced the traditional methods because of their lower deposition rate.

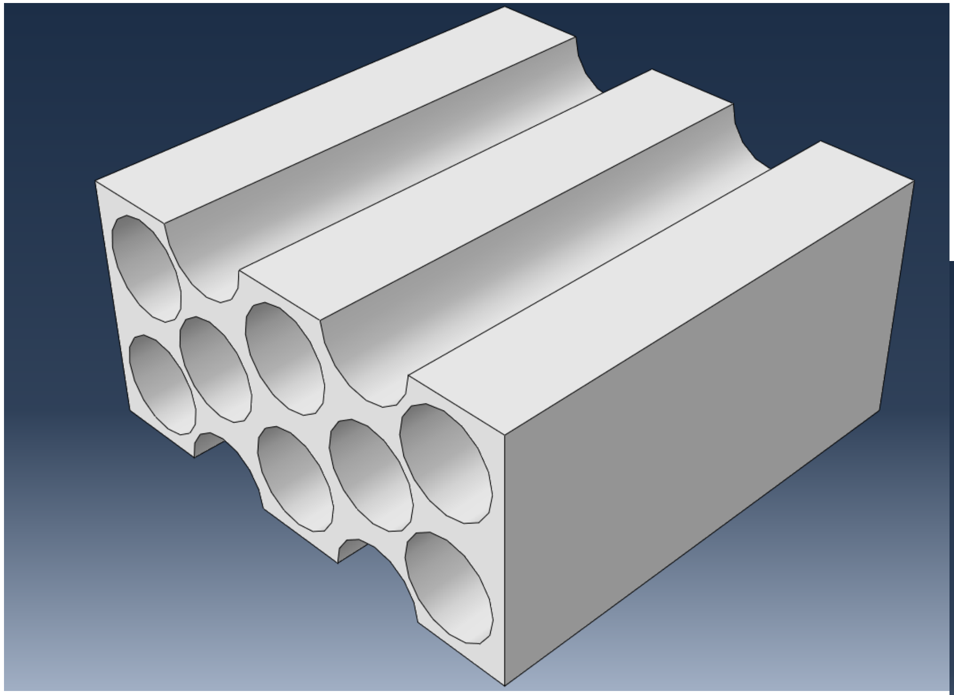
Composite Structure

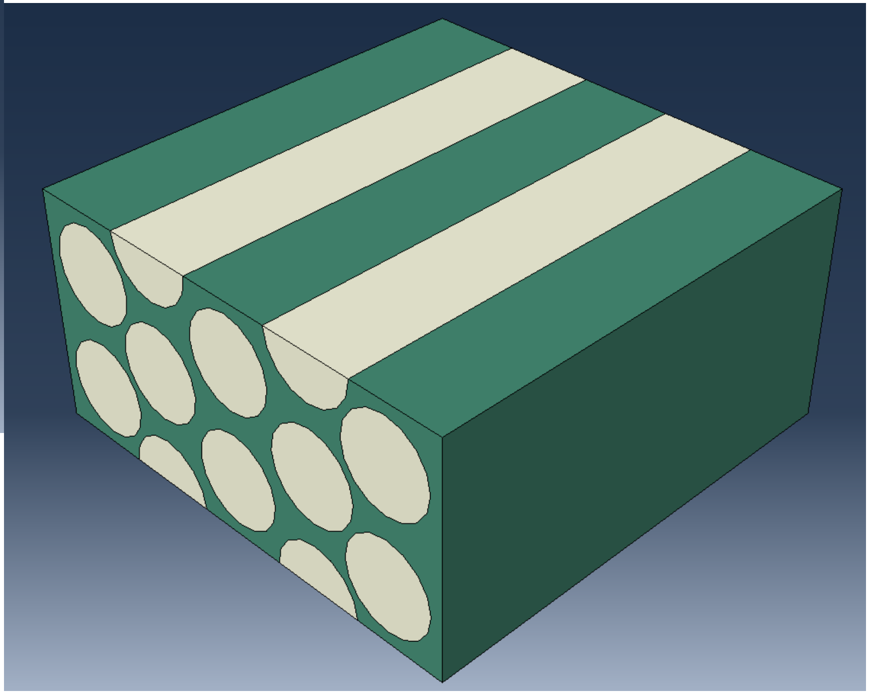
- **Fiber to Matrix Ratio or Volume Fraction**
  - **Matrix dimensions = 0.05mm x 0.025mm x 0.05mm**
  - **Fiber diameter = 0.01 mm**
  - **Fiber length = 0.05 mm**
  - **Volume fraction = Volume of fibers/Total volume of composite = 63%**
- **Fiber arrangement in Abaqus**



Composite Structure

- **Matrix**





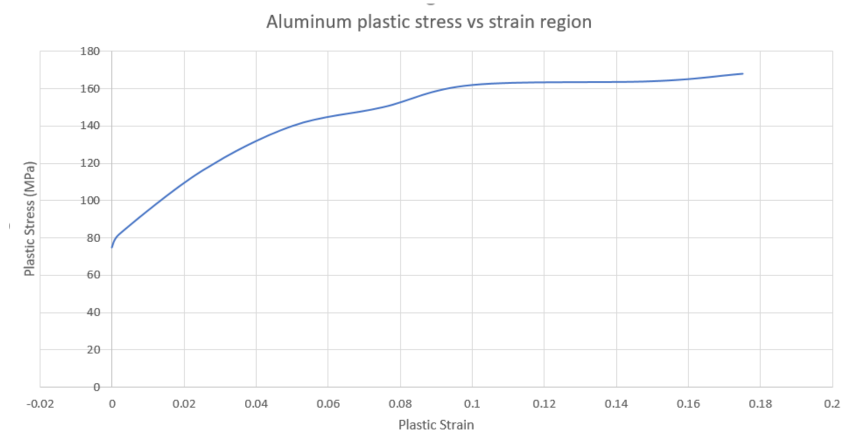
Material Properties

- **Epoxy – Viscoelastic**
- **eGlass – Elastic**
- **Aluminum – Elastic/Plastic**
- **Steel 355 – Bi-linear**

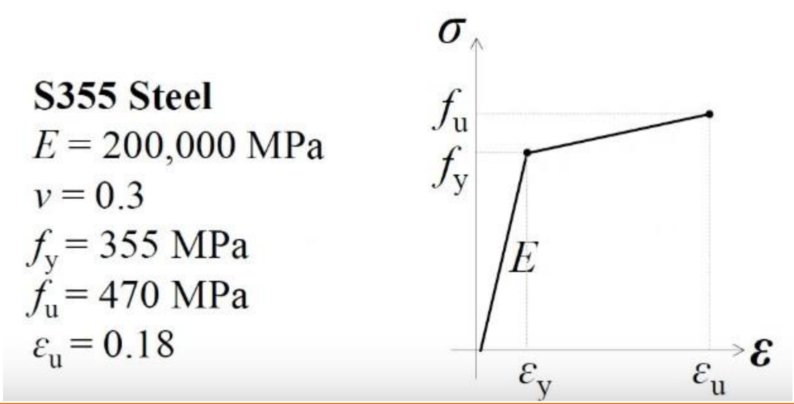
Material	Density (g/cm^3)	Elastic Modulus (MPa)	Poisson's Ratio
Epoxy	1.18	4060	0.37
eGlass	2.58	72300	0.2
Aluminum	2.71	68000	0.3
Steel 355	7.85	200000	0.3

Plastic Models

- **Aluminum – Plastic stress vs strain**



- **Steel – Bilinear curve with hardening**



Viscoelastic Model

- **Epoxy – Viscoelasticity defined with Prony series**

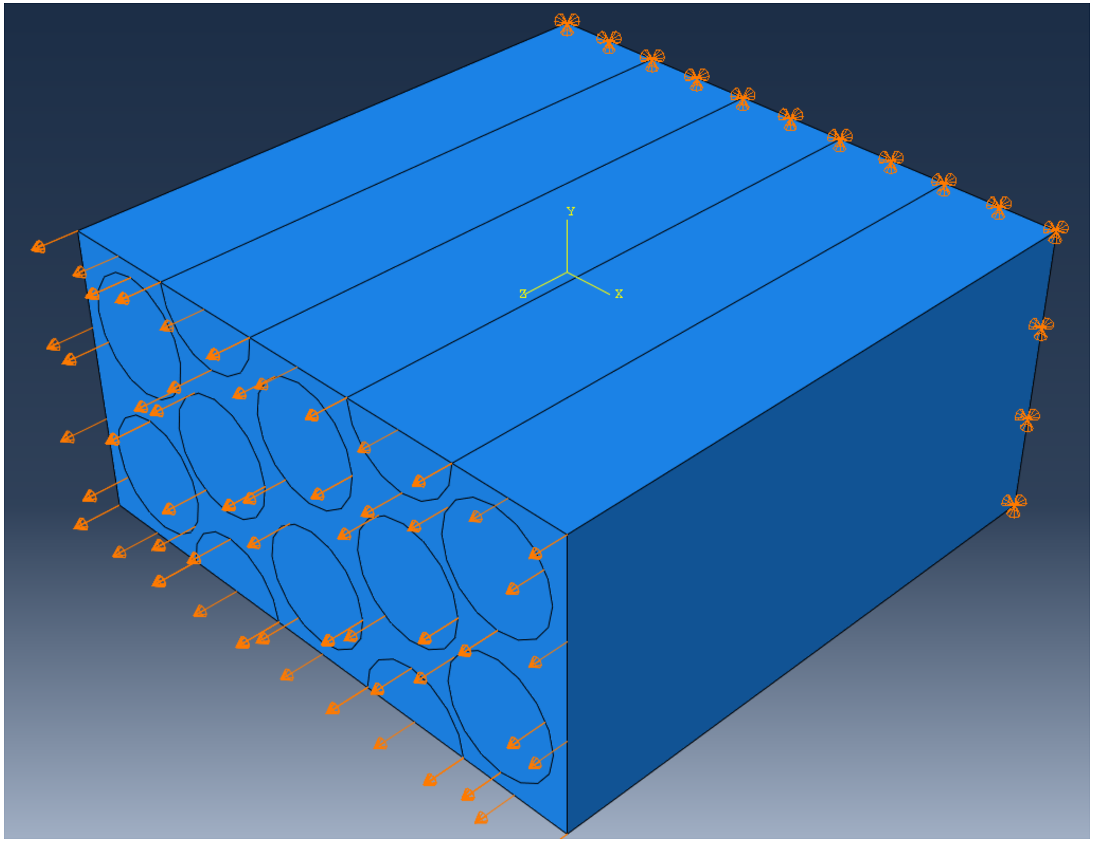
g_i	τ_i
0.0738	463.4
0.1470	0.06407
0.3134	0.0001163
0.3786	7.321e-7

Comparitive Study of Composites

- **Using the material models shown previously, two composites were modeled in Abaqus for a comparative study –**
  - **GFRP: Matrix – Epoxy, Fiber – eGlass**
  - **Metal Matrix Composite: Matrix – Aluminum, Fiber – Steel**
- **The following mechanical properties will be compared in 2 directions (composites are anisotropic) when a displacement of 0.01 mm is applied to simulate tension**
  - **Von Mises stress**
  - **Strain**
  - **Displacement Magnitude**
- **The contour plots can be used to identify regions of high stress which can be prone to failure**

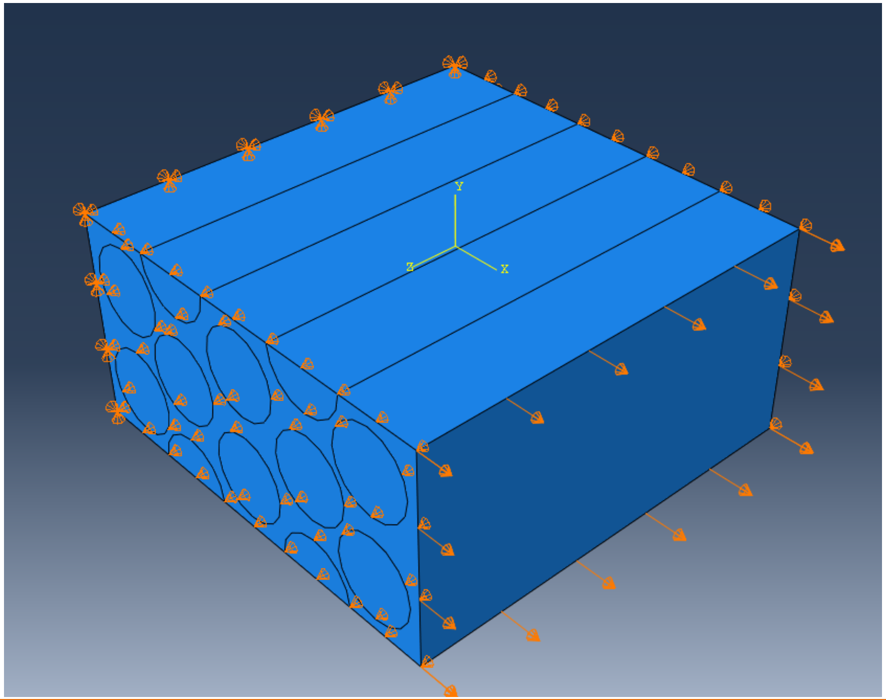
Boundary Conditions & Loads

- **Tension along the fiber direction**
  - **BC – No translation at the back face (y-x plane) of the composite**
  - **Load - z-axis displacement of 0.01 mm on the front face (y-x plane) of the composite**



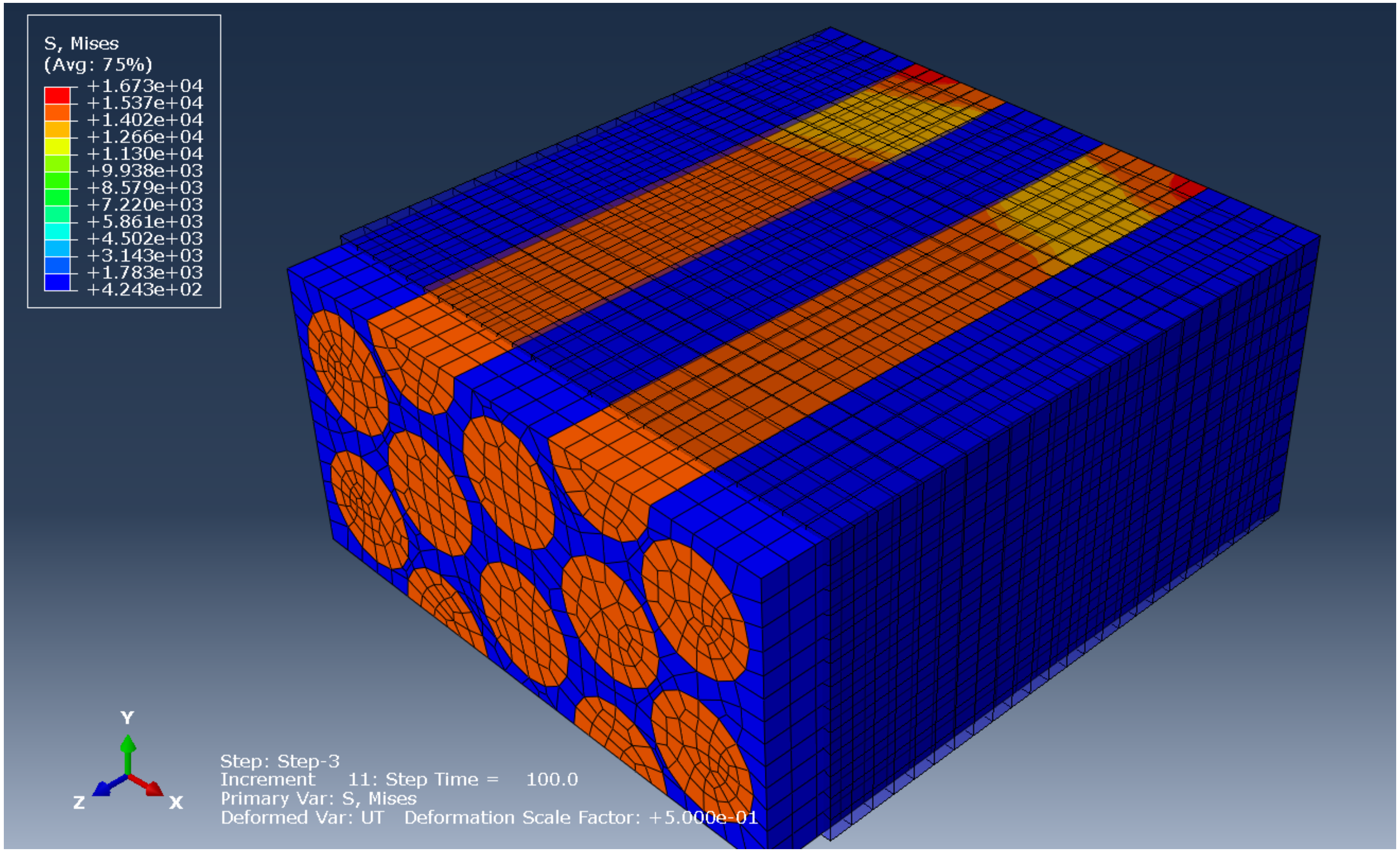
Boundary Conditions & Loads

- **Tension transverse (against) to the fiber direction**
  - **BC – No translation on the opposite surface of the tensile stress, no *z*-axis translation (along the fiber direction) on the front and back surfaces (x-y plane)**
  - **Load – x-axis displacement of 0.01 mm of the front surface (y-z plane)**



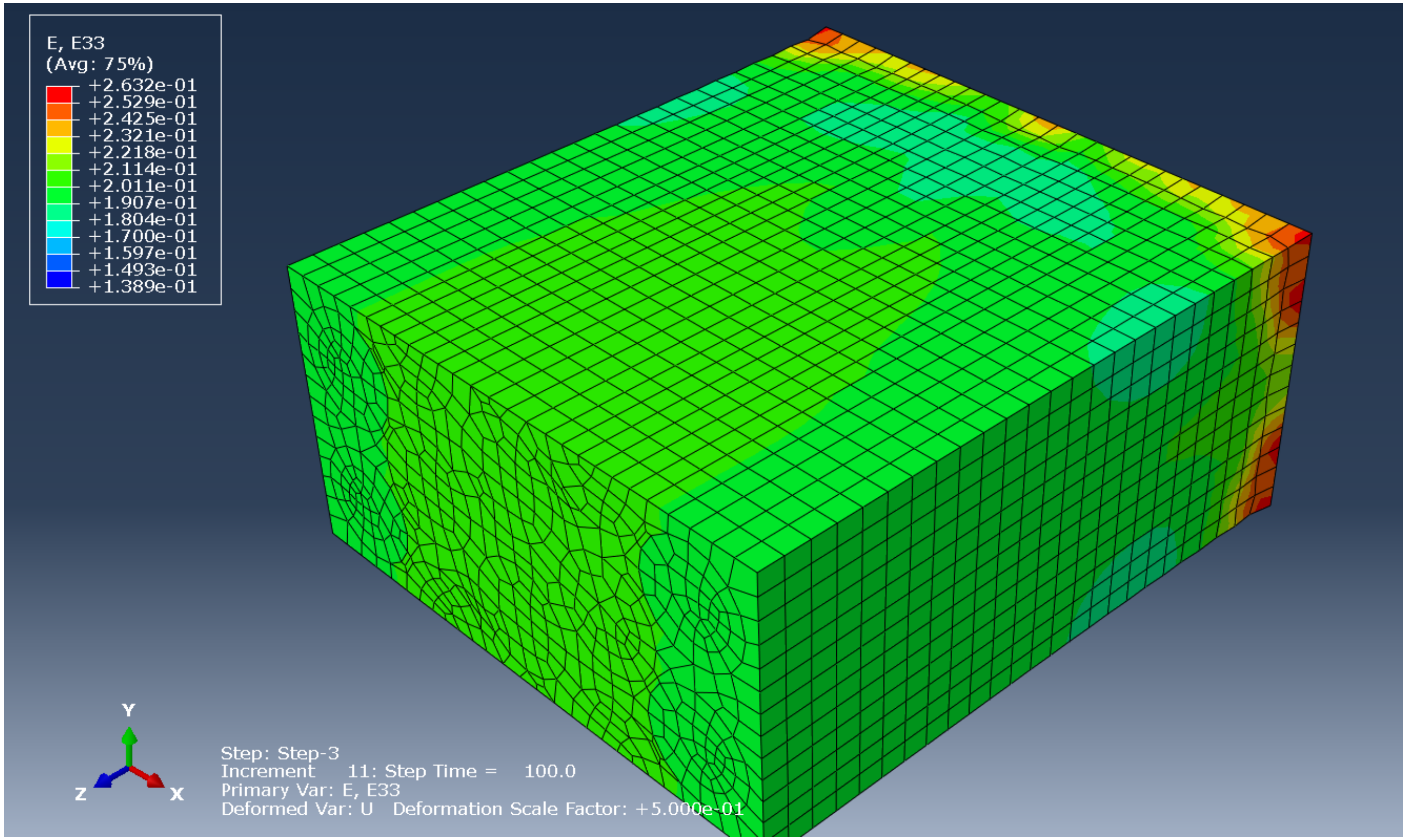
Results – GFRP in tension along the fibers

- **Von Mises Stress**



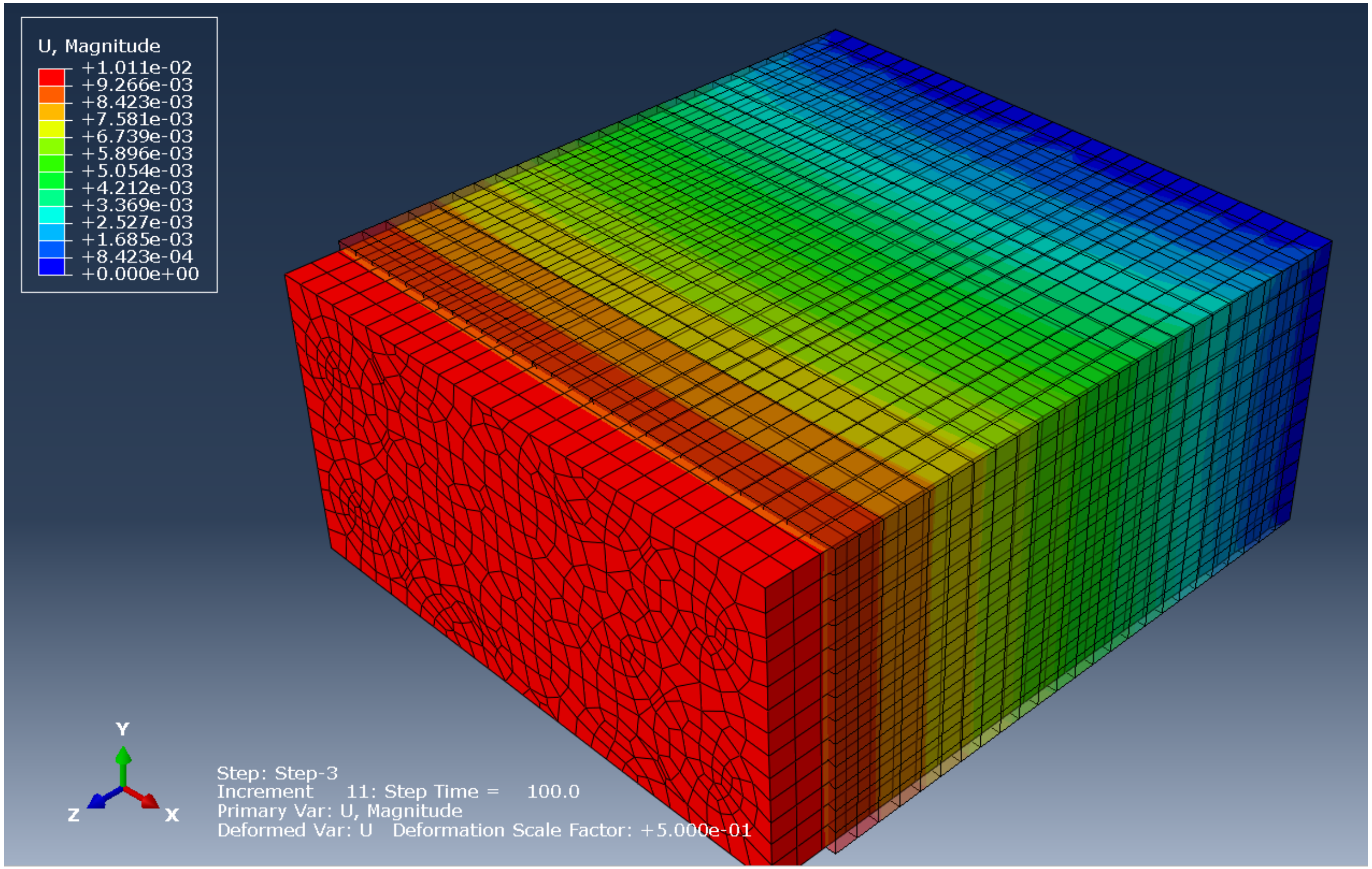
Results – GFRP in tension along the fibers

- **Strain in z-direction**



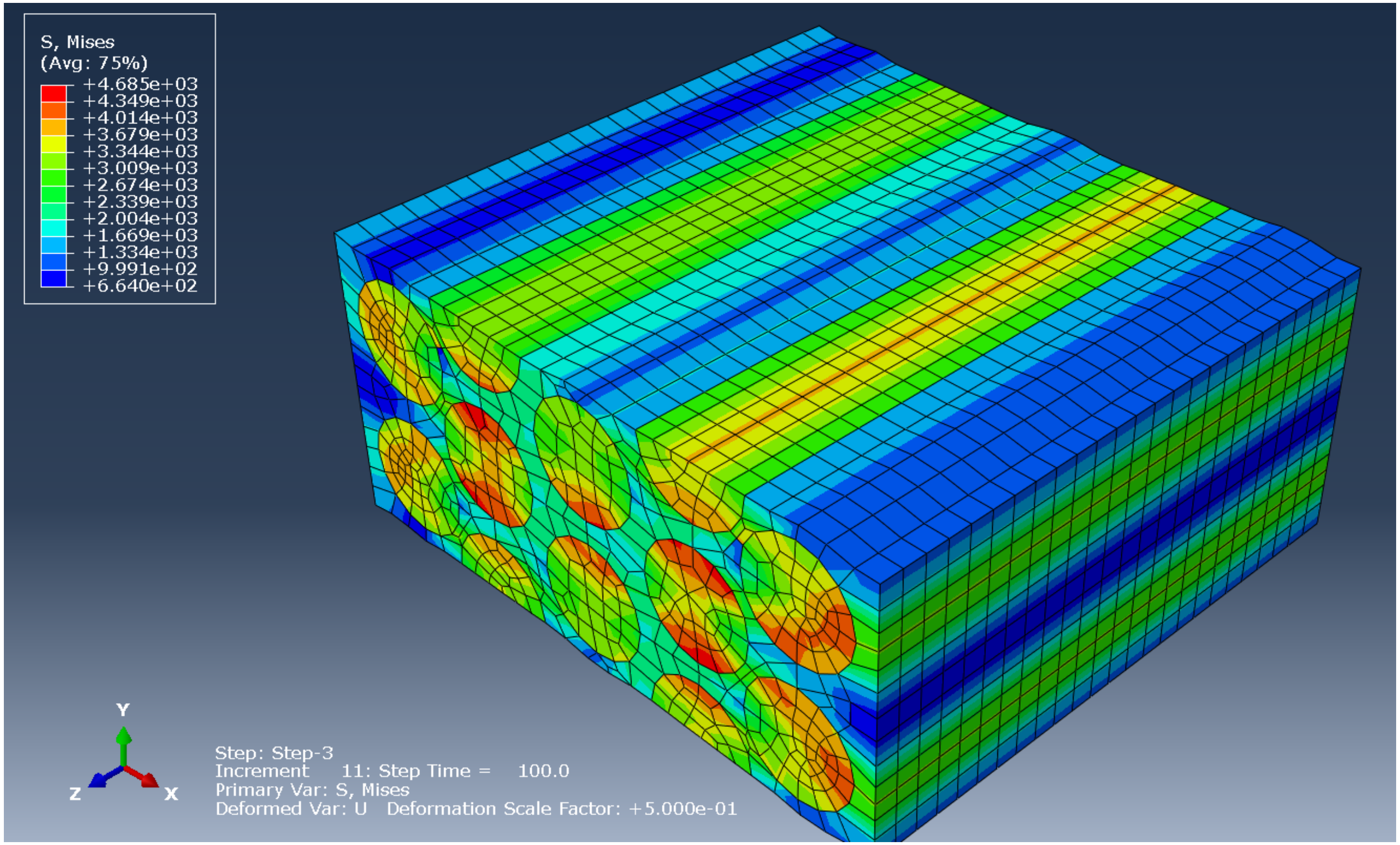
Results – GFRP in tension along the fibers

- **Displacement Magnitude**



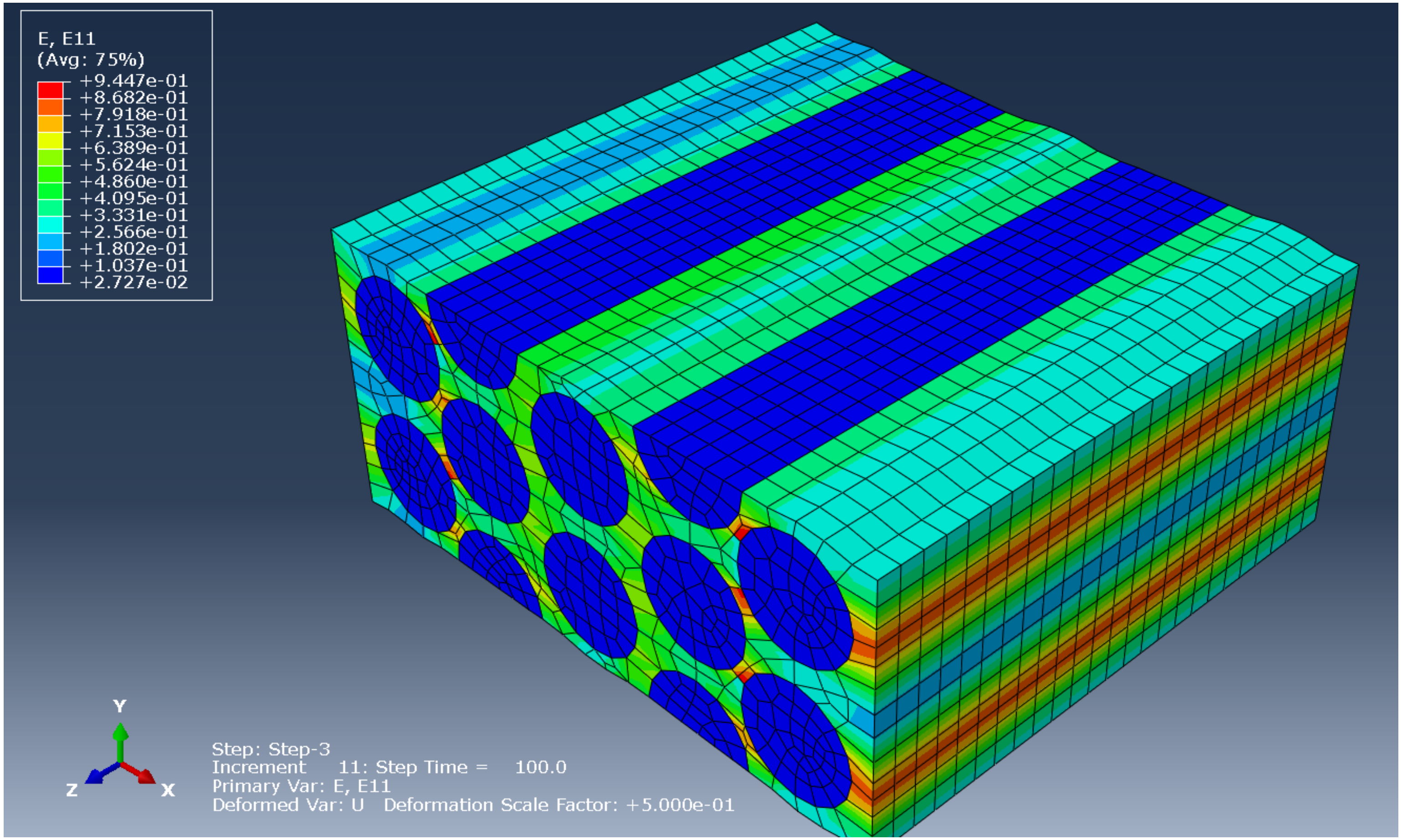
Results – GFRP in tension against the fibers

- **Von Mises Stress**



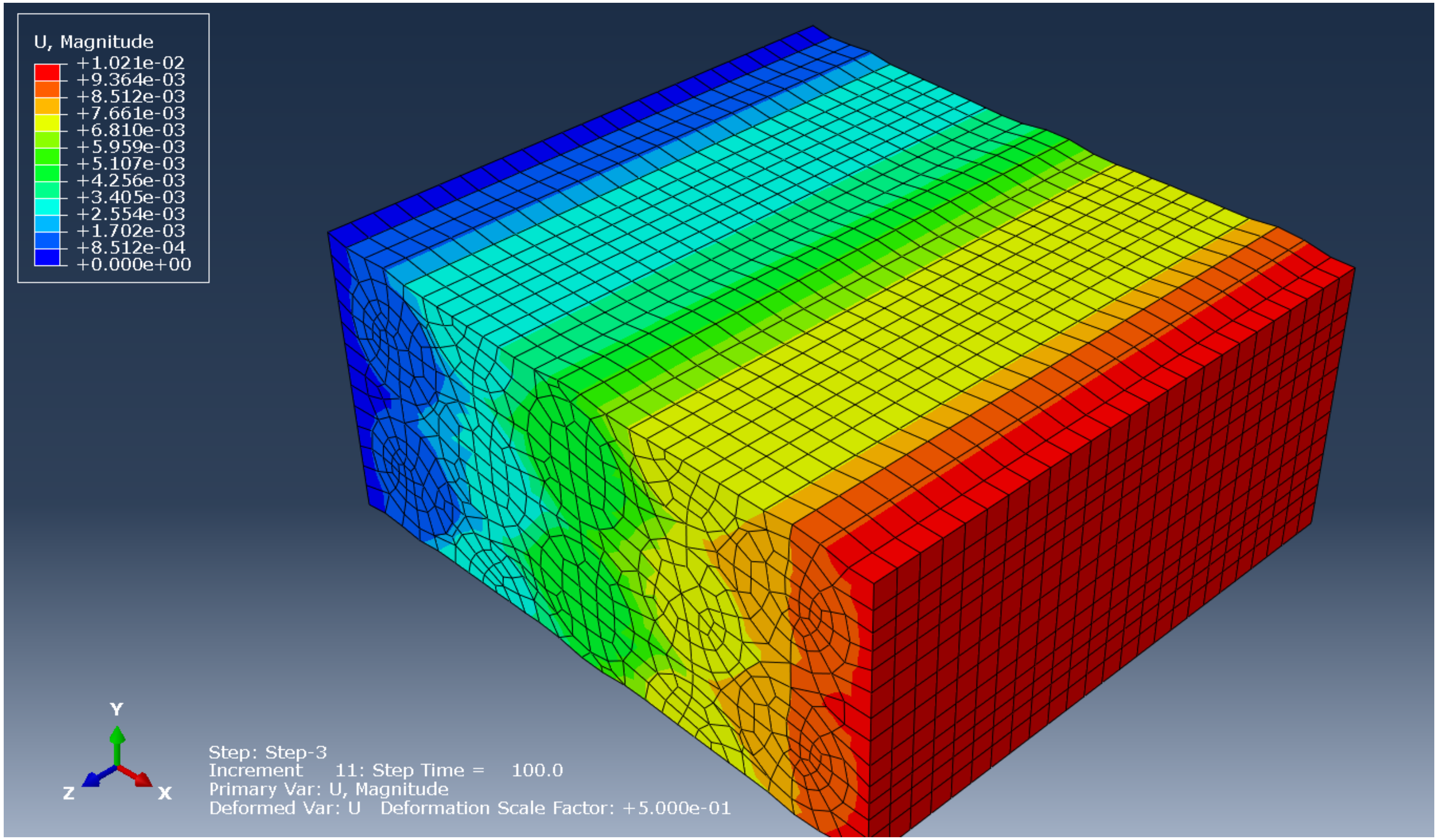
Results – GFRP in tension against the fibers

- **Strain in x-direction**



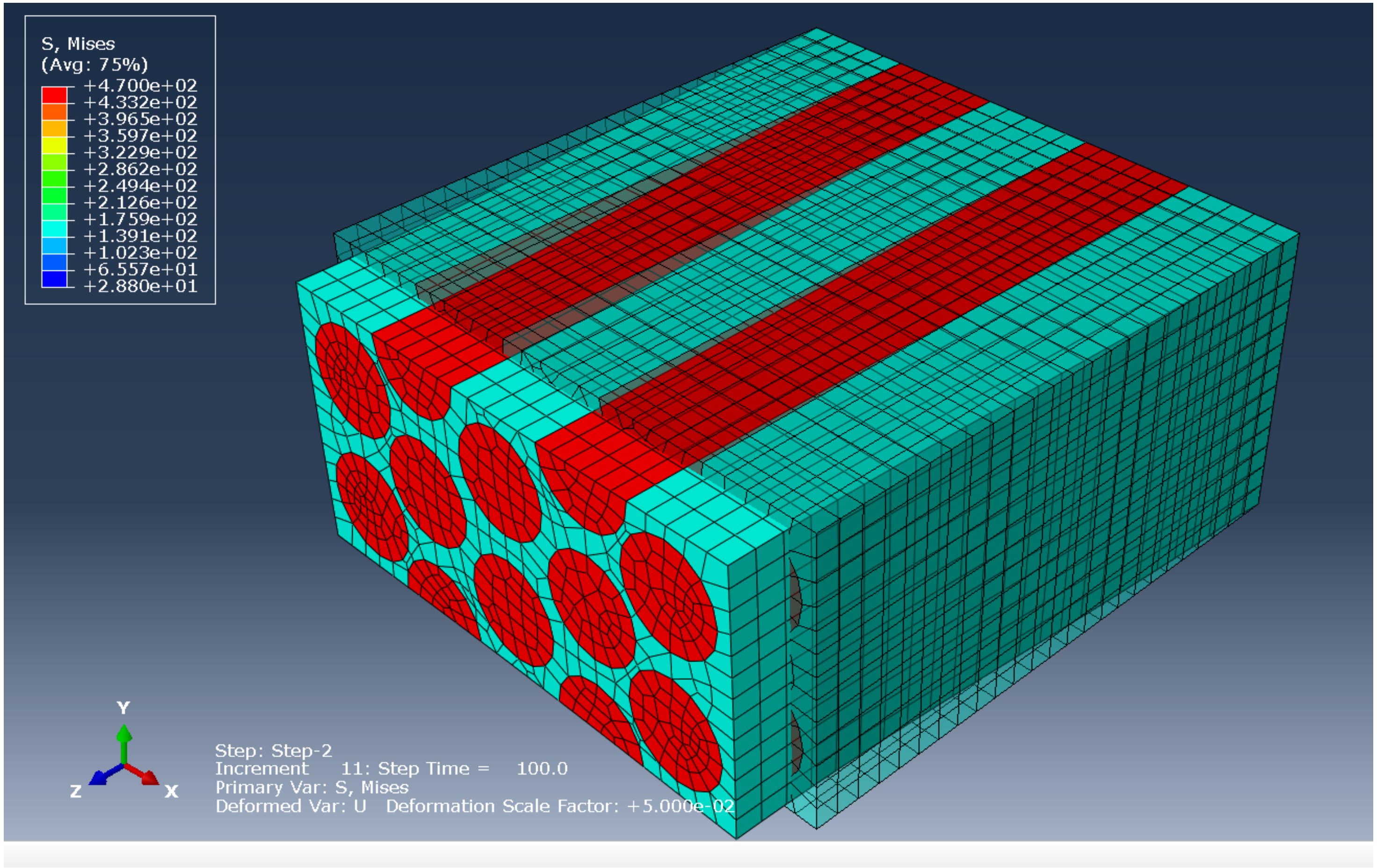
Results – GFRP in tension against the fibers

- **Displacement Magnitude**



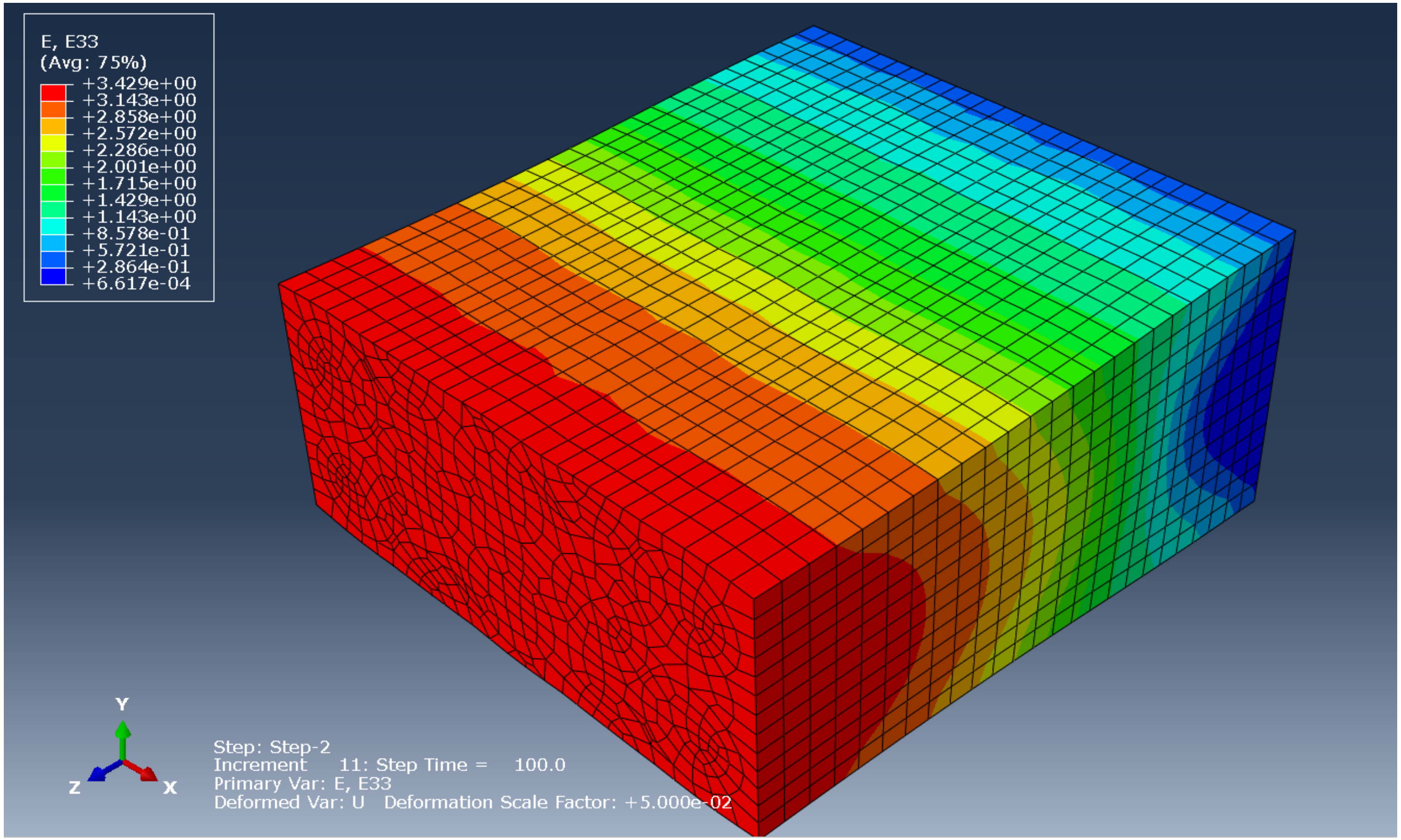
Results – Metal-Matrix Composite in Tension along the fiber

- **Von Mises**



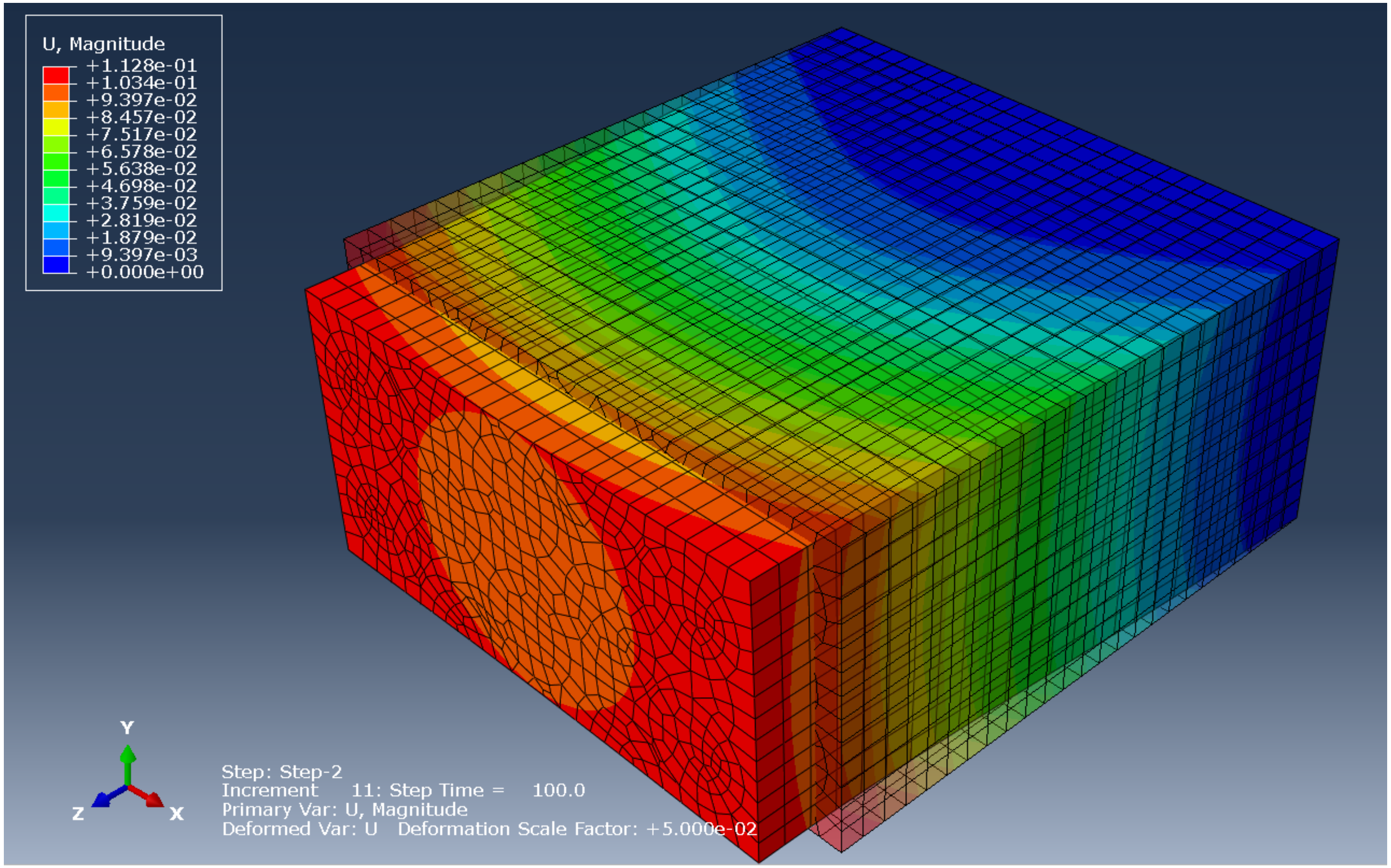
Results – Metal-Matrix Composite in Tension along the fiber

- **Strain in z-direction**



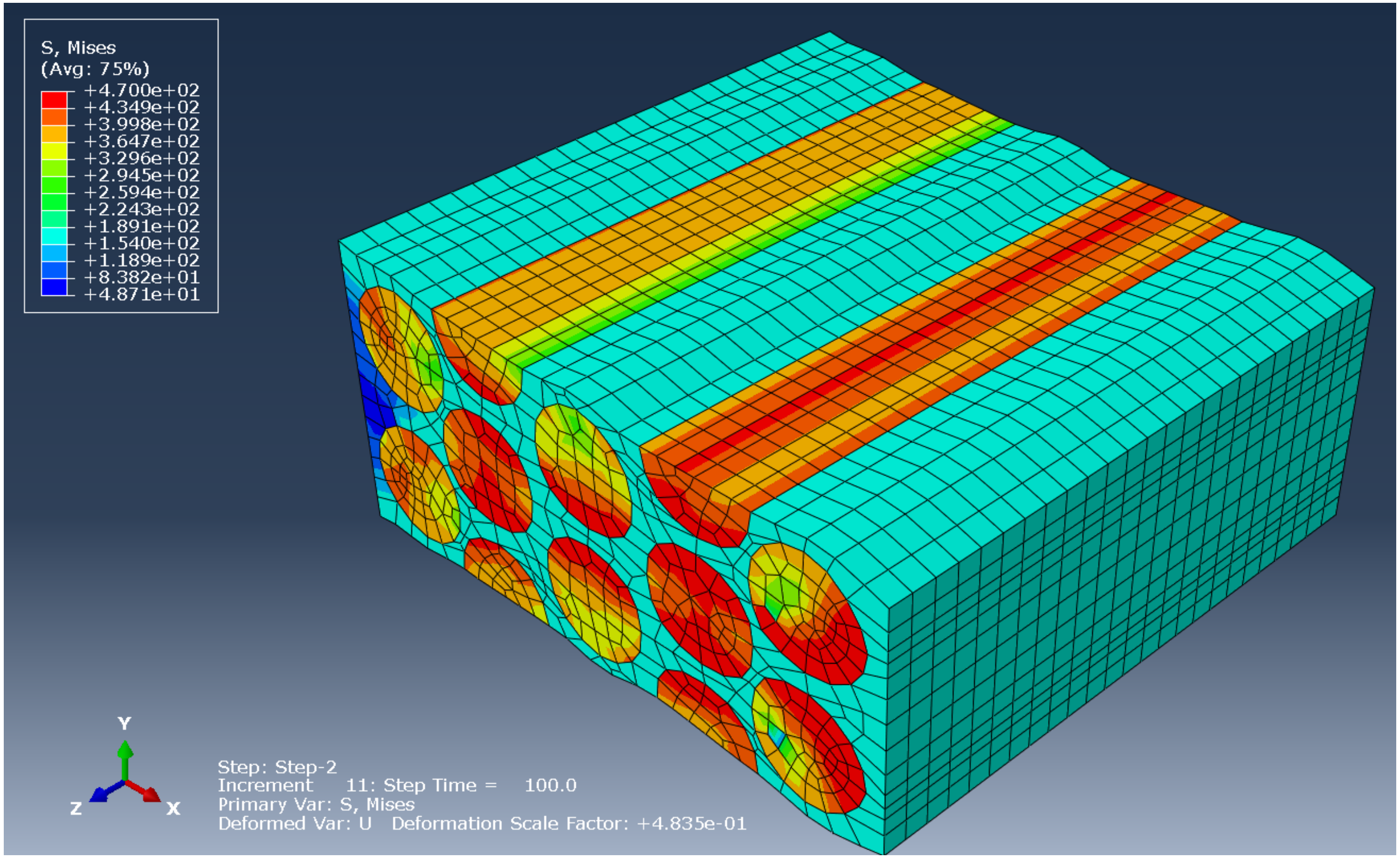
Results – Metal-Matrix Composite in Tension along the fiber

- **Displacement Magnitude**



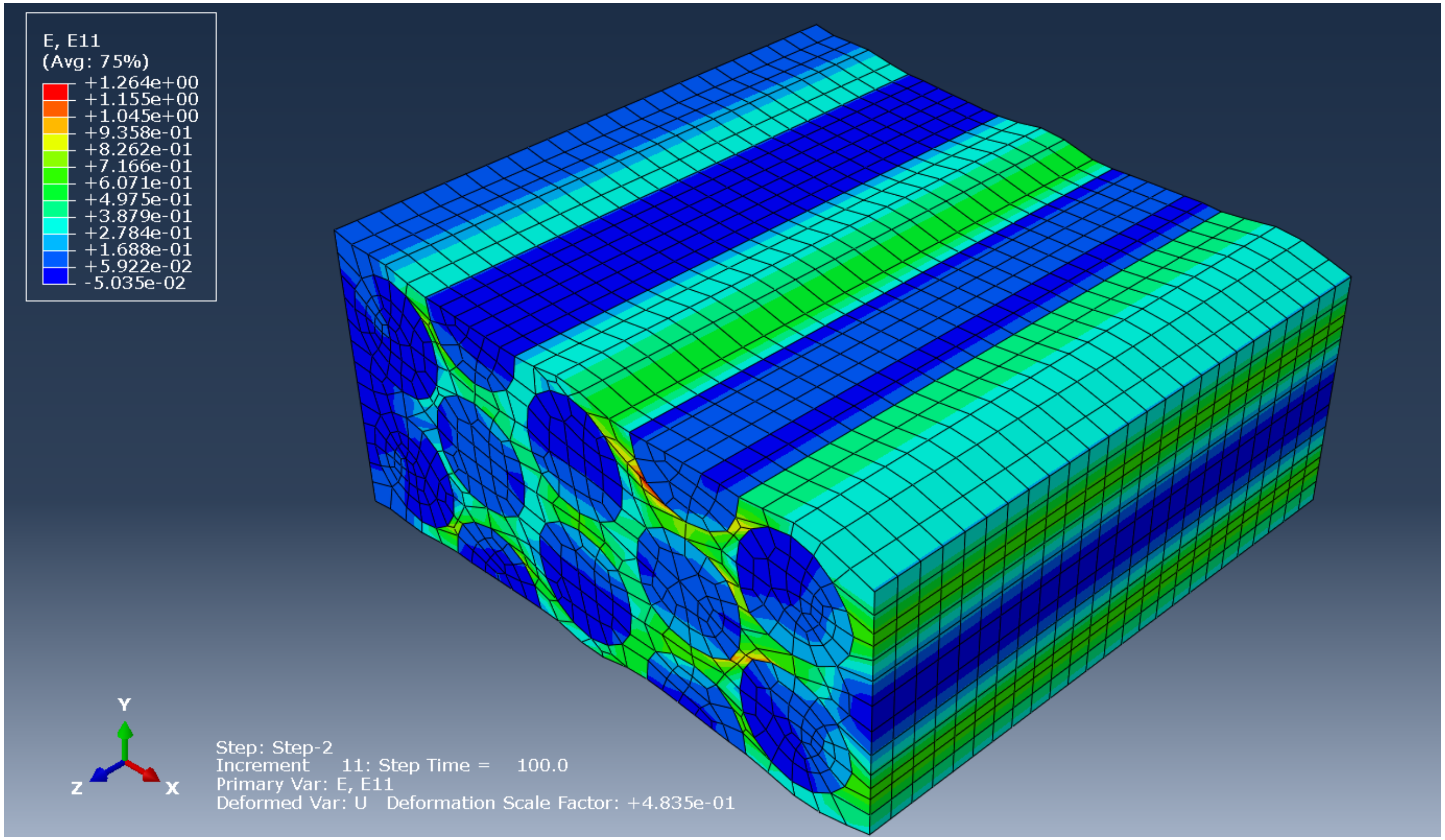
Results – Metal-Matrix Composite in Tension against the fiber

- **Von Mises**



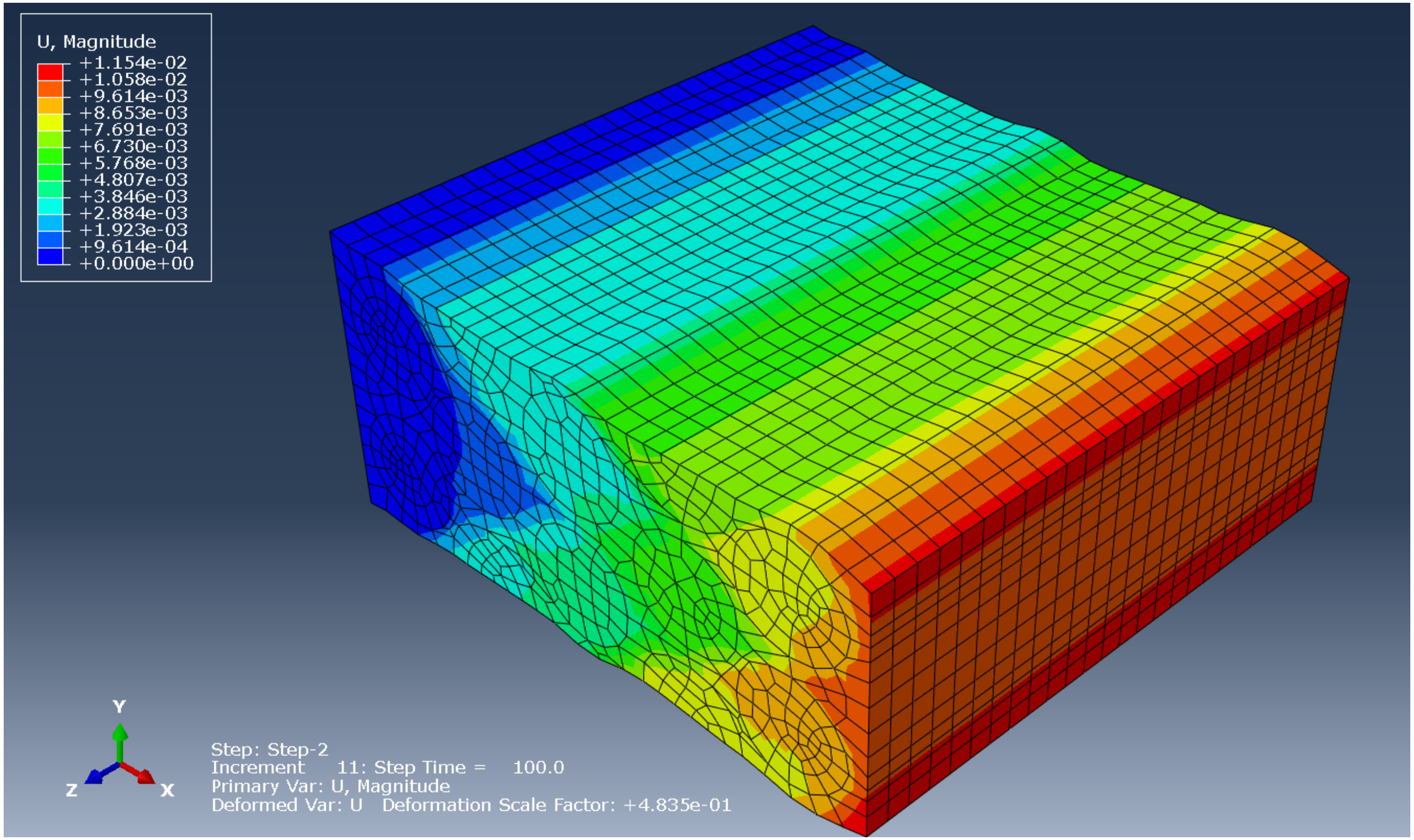
Results – Metal-Matrix Composite in Tension against the fiber

- **Strain in x-direction**



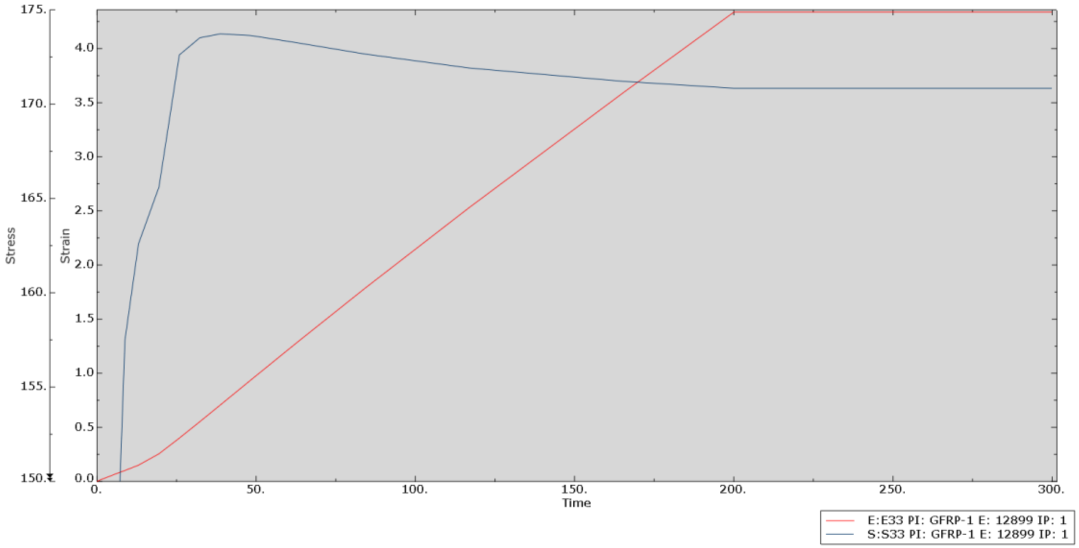
Results – Metal-Matrix Composite in Tension against the fiber

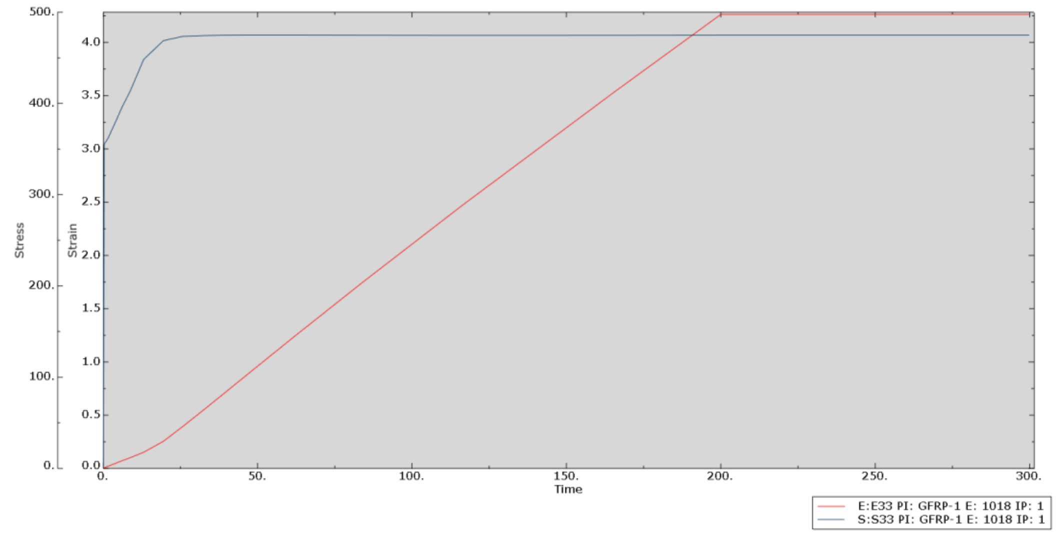
- **Displacement Magnitude**



Transient Stress & Strain

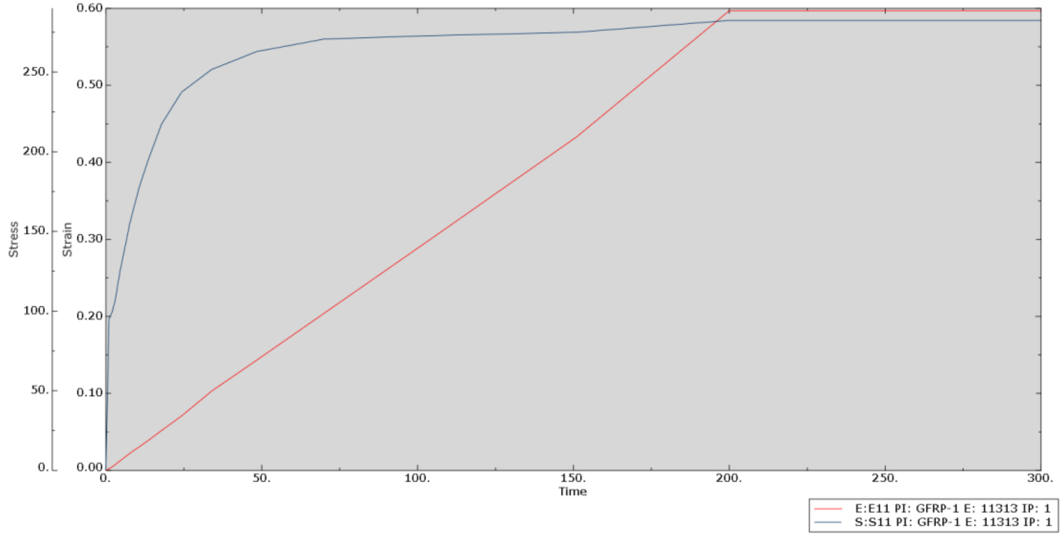
- **Tension along the fibers (Al on top, steel on bottom)**

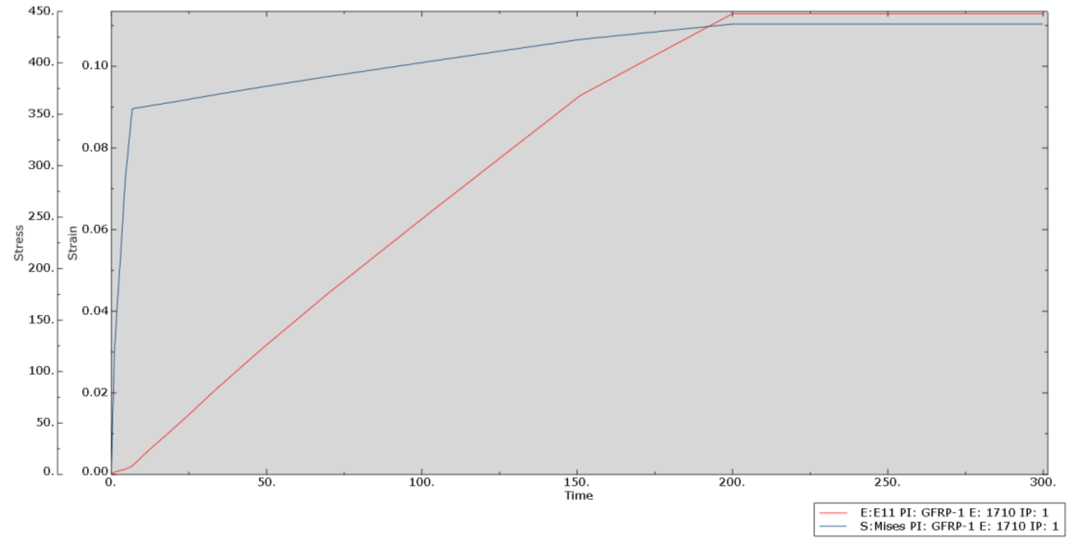




Transient Stress & Strain

- **Tension against the fibers (Al on top, steel on bottom)**





Results

- **Results table**

Composite	Von Mises Stress (MPa)	Strain (%)	Displacement Magnitude
GFRP (along fiber)	1.673 x 10^4	0.263	1.011 x 10^-2
GFRP (against fiber)	4.685 x 10^3	0.945	1.012 x 10^-2
Al-Steel (along fiber)	4.7 x 10^2	3.429	1.128 x 10^-1
Al-Steel (against fiber)	4.7 x 10^2	1.264	1.154 x 10^-2

Processing Challenges

- **Interfacial bonding - Layer adhesion of additively manufactured composites is not strong – This adds further anisotropicity in the composite**
- **Porosities**
- **Low yield for simple parts**
- **Process parameters like raster angle, infill speed, layer thickness, nozzle temperature, etc. affect the porosity, shrinkage, and microstructure of the composite. Thus, impacting ductility, toughness, Young's modulus, and strength.**
- **Material limitations – each AM process has materials limitations. Example – In FDM, thermoplastics are used**

References

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Thank you!

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