Experimental and Static Structural Analysis of AHSS Material with Varying Slenderness Ratios Using Split Hopkinson Pressure Bar

G Keerthi[1], T Ramamohan Rao [2], K. Saraswathamma [3]

University College of Engineering, Osmania University, Hyderabad, India

[2]Vasavi College of Engineering, Hyderabad, India

3University College of Engineering, Osmania University, Hyderabad, India

Abstract:- Material behavior at high strain rates is frequently characterized using the Split Hopkinson Pressure Bar Tests. It is a key testing tool for materials' dynamic mechanical characteristics. In the SHPB test, the material properties obtained are influenced by the specimen's shape. It is important to select the specimen dimensions understanding the behaviour. This study examines how strain and stress values are affected by varying the specimen diameter. The outcomes of the experiments were compared and verified using Ansys. In this study 5mm, 6mm, 7mm, 8mm and 10mm cylindrical specimens of Advanced High Strength Steels (AHSS) were tested under 0.5Mpa, 1Mpa and 1.5 Mpa along with different slenderness ratios. The length (L) of the specimens and the bar requirements were unaltered. The results showed that when the specimen's area decreased, the reflected ratio increased while the transmitted ratio decreased. By altering the specimen diameter, it was demonstrated that the impedance relationship and strain rate could be changed without altering the bar's actual size or composition. The input stress-strain curve and the actual computed stress-strain states in the specimen are compared with the stress-strain behaviour of the specimen, which is reconstructed using the pressure bars' calculated response.

Keywords: Advanced high strength steels, Split Hopkinson Pressure Bar, High strain rate.

1. Introduction

AHSS stands for Advanced High Strength Steels. Because of its exceptional strength-to-weight ratio, Advanced High Strength Steels (AHSS) are being utilized more in the automotive sector to create lighter and safer automobiles. They make it possible to build thinner, more effective components and provide better crash energy management. Structural elements, bumper systems, seats, and doors are among the main uses, and as technology develops, new applications are always added. Unlike traditional high-strength steels, which frequently compromise one for the other, AHSS achieves both high strength and ductility. AHSS permits the use of thinner components without sacrificing safety, vehicles can weigh less and consume less fuel. By absorbing greater impact energy, AHSS improves crash safety and shields passengers from harm in crashes. Applications like car manufacturing, where they are subjected to high-speed impacts or collision occurrences, frequently use AHSS. By simulating these dynamic stress situations, SHPB enables researchers to precisely evaluate the material's response. The elongation, ultimate tensile strength, and dynamic yield strength of AHSS under high strain rates can all be determined using SHPB testing. For precise simulations and to forecast how AHSS components will behave in practical applications, this knowledge is crucial. The information gathered from SHPB tests can be utilized to verify and improve material models, which are mathematical depictions of the behaviour of a material. The accuracy of computer simulations used in engineering design depends on this validation.

Split Hopkinson Pressure Bar (SHPB) devices used in uniaxial compression experiments are commonly used to assess the stress-strain response of engineered materials at high strain rates [1]. This technique has been applied extensively to metals like steel, copper, and aluminum. The dynamic mechanical reaction of a material is more complex and exhibits a range of characteristics, such as strain rate sensitivity, rate-dependent plasticity, and energy dissipation. Understanding these dynamic mechanical properties is crucial for many engineering applications, such as safety systems, impact-resistant materials [2], high-speed performance optimization, and structural design [3,4]. Numerous materials, such as metals [5], polymers, composites, ceramics, and rocks [6,7], have been well described by the dynamic response [8,9] and failure of split Hopkinson pressure bar (SHPB) and split Hopkinson tension bar (SHTB) [10] under uniaxial stress [11] modes. Many researches have been conducted tests on rocks, polymers, composites, titanium Grade 1, ceramics and many more. Impact tests are not done on AHSS using SHPB tests, hence in this work investigations are done to understand the effect of specimen diameter using SHPB are conducted.

2. Materials and Methods

2.1 AHSS

Advanced High Strength Steel material is evaluated in a cylindrical shape with different L/D ratios in standard SHPB testing. The cross-sectional area of the specimen is a significant component of the impedance relationship and is anticipated to directly affect the SHPB test. In the experiment, specimens with diameters of 5, 6, 7, 8, and 10 mm were employed; each specimen measured 10 mm in length. By varying the specimen diameter while keeping the length constant, the impact of diameter was evaluated and material properties at different strain rates were determined.

The pressure of the pneumatic launcher was set to 0.5, 1.0, and 1.5 bar. By using the S-S curves from each test to generate dynamic compression curves, the influence of the diameter and the material parameters obtained from the trials were further verified.

By changing the AHSS specimen's diameter during the dynamic compression test, the stress wave analysis was carried out. Figure 1 displays the specimens used in SHPB tests. Table 1 shows the specimens' dimensions and slenderness ratio (L/D).

Figure 2.1: Cylindrical specimens of AHSS with varying diameters (5, 6, 7, 8, and 10 mm).

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Table 1: Diameters, Lengths and Slenderness ratios of AHSS specimens

Specimen	**Diameter(mm)**	**Length(mm)**	**Slenderness Ratio**
Case 1	5	10	2
Case 2	6	10	1.66
Case 3	7	10	1.42
Case 4	8	10	1.25
Case 5	10	10	1.0

Mechanical characteristics include strong elongation, bake-hardening tendency, and high yield and tensile strengths. Additionally, they can be made to attain strength-ductility balances and have an exceptional strain hardening capacity.

Table 2: Mechanical Properties of AHSS material

Density (kg/m3)	Velocity of sound(m/s)	Velocity of Light(m/s)	Young's Modulus(N/m^2)	HSSN code
7800	5900	$1.5*10^8$	$1.9*10^{11}$	7228

2.2 SHPB EQUIPMENT AND THEORY:

The SHPB apparatus includes specimens, a striker, an incidence bar, a transmission bar, and data collection devices (Figure 1). The striking bar is fired by the gas pistol. When it hits the incident bar at a velocity of V0, it produces compressive elastic waves [20]. Photogate voltage signals obtained from strain gauges placed on the incident and transmitted bars are utilized to quantify the elastic waves flowing through them, and V0 is measured using an oscilloscope and amplifier. Because of the impedance difference, the incident wave splits into transmitted and reflected waves after passing through the interface between the specimen and the incident bar [21]. Pulses can be classified as incident ($\varepsilon_I(t)$), reflected ($\varepsilon_R(t)$), or transmitted ($\varepsilon_T(t)$). The specimen's stress (σ_S), strain (ε_S), and strain rate (ε_S) are calculated using SHB theory and engineering relationships.

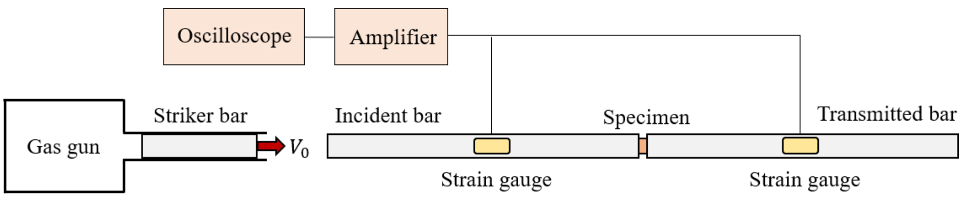

Figure 2.2: Schematic of the Split Hopkinson pressure bar equipment.

$$\sigma_S(t) = \frac{A_B}{A_s} E_B \varepsilon_T(t), \qquad (1)$$

$$\varepsilon_S(t) = -2\frac{C_B}{L_S}\int_0^t \varepsilon_R(t)dt, \quad (2)$$

$$\dot{\varepsilon}_S(t) = -2\frac{C_B}{L_S}\varepsilon_R(t), \quad (3)$$

where A_S, A_B, E_B, L_S, and C_B stand for the specimen's area, the pressure bar's area, the specimen's thickness, the Young's modulus of bars, and the pressure bar's elastic wave speed, respectively. Given the specimen's uniaxial and uniform stress, the equations [22] satisfy the stress equilibrium condition, which is ($\sigma_I+\sigma_R=\sigma_T$).

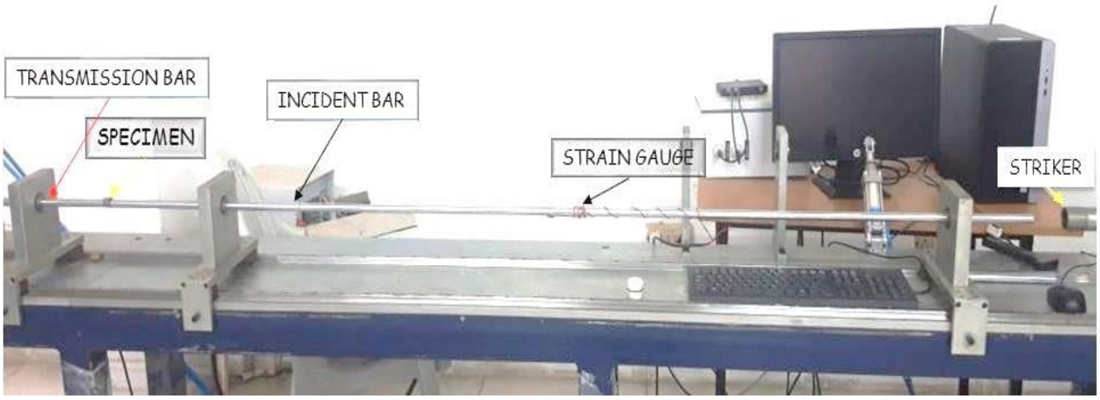

Figure 2.3 Split Hopkinson Pressure Bar Equipment.

Some fundamental presumptions form the basis of SHPB analysis. (i) The one-dimensional wave propagation theory describes the waves moving through the bars. (ii) The specimen's axial stress and strain fields are uniform. (iii) In the compression test, the friction effect and the specimen inertia effect are insignificant.

Table 3: Dimensions of the SHPB pressure bar.

	Length (mm)	**Diameter (mm)**
Striker bar	200	20
Incident bar	1200	20
Transmitted bar	1200	20

2.3 THE SHPB TESTS WAVE IMPEDANCE

In order to perform the SHPB test, one-dimensional (1D) stress waves must pass through materials like pressure bars and specimens. Through the incident bar, the stress wave meets the relevant material specimen. The incident pulse passes through the specimen, with a portion of it being reflected at the contact between the specimen and the incident bar. It is possible to determine the material properties of the specimen by analysing the transmitted and reflected stress waves. It is also possible to express them as the impedance relationship ($Z = A\rho C$), where A is the cross-sectional area, ρ is the density, and C is the 1D wave velocity of the medium. Because the incident and striker bars in SHPB tests usually have the same cross-sectional area and are made of the same material, stress waves are transmitted without reflection. However, the impedance difference between the bars and the specimen causes the incident wave to be divided into transmitted and reflected waves. The strain gauges on the incident and transmitted bars provide voltage signals that can be used to measure the transmitted and reflected waves, respectively.

Making separate bars for each specimen was expensive and inefficient, so we tried altering the pressure bar to alter the impedance ratio. ASTM standards currently give specifications for specimens used in quasi- static tensile tests. In testing, the diameter and length of the cylindrical specimen mostly dictate its shape. Changes in the diameter may also result in changes in the initial impedance. The ratio of transmitted to reflected light can be changed by adjusting the cross-sectional area. This study examined the impact of changing the diameter while maintaining a constant length.

2.4 STRUCTURAL STATIC ANALYSIS USING ANSYS

A static analysis accounts for inertia and damping effects, such as those brought on by time-varying loads, and computes the effects of steady loading conditions on a structure. However, time-varying loads that may be roughly represented as static equivalent loads (like the static equivalent wind and seismic loads often defined in many building codes) and steady inertia loads (such gravity and rotational velocity) can also be included in a static analysis. Static analysis calculates the forces, stresses, strains, and displacements in components or structures brought on by loads that don't significantly affect damping and inertia. We assume steady loading and response circumstances, meaning that the loads and the reaction of the structure change gradually over time.

3 Results and Discussions

According to the results of the SHPB tests, the stress-strain curve for AHSS material under various impact loading circumstances is shown. To acquire extremely reliable material properties, it is necessary to repeat tests under the same conditions to confirm the repeatability of the obtained strain signals. An air compressor valve is used to regulate and lock the air pressure at the start of the test in order to assess the experiment under air pressures between 0.5 and 1.5 MPa. Figure 4(i), 4(ii) and 4(iii) represents the stress vs strain graphs with the varying pressures of 0.5, 1.0 and 1.5 bar respectively.

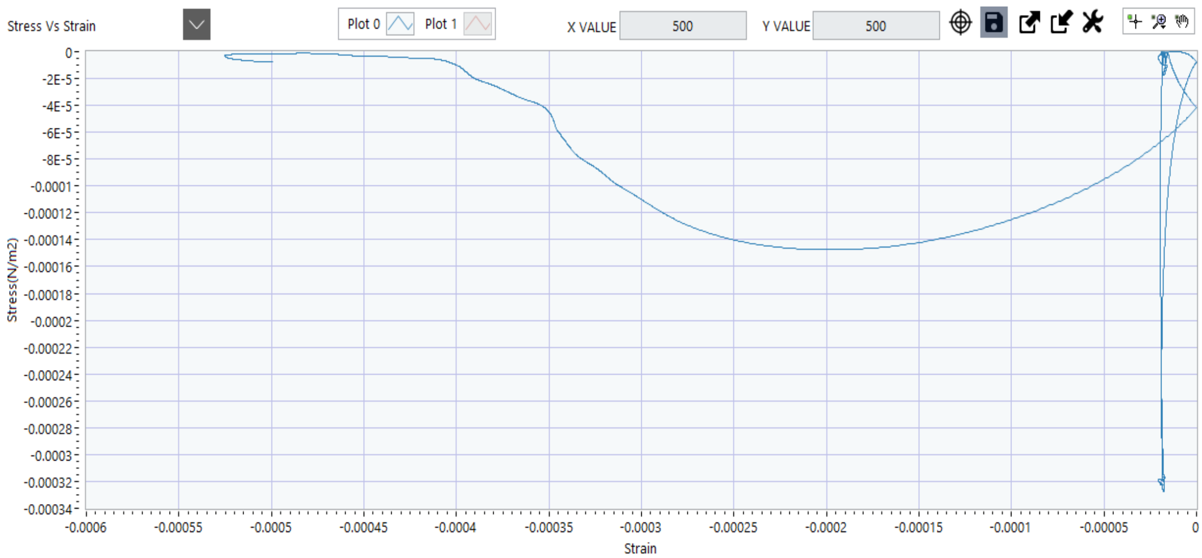

Figure 3.1 Stress vs Strain with the pressure 0.5 Bar.

Figure 3.2 Stress vs Strain with the pressure 1 Bar.

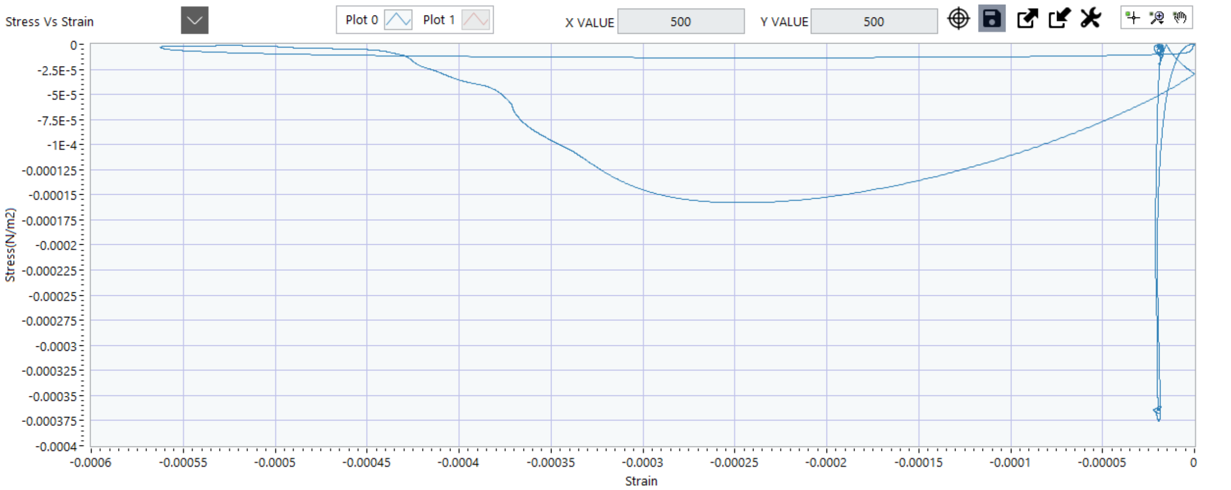

Figure 3.3 Stress vs Strain with the pressure 1.5 Bar.

As we can see, the stress in the material rises initially and peaks at a modest strain rate before falling as the wave leaves the transmission end. Figure 5 shows the graphs transmitted and reflected waves that were measured in each specimen at various pressures and diameters. Even when the experiment was conducted under the identical conditions, the specimen distorted at a higher-strain-rate zone when the diameter was reduced. However, when the 10 mm-diameter test was performed under any conditions, a significant variance was seen after the first strain rate segment. In contrast, a smaller diameter causes the deviation to reduce, the strain rate to increase, and a wider range of strain to be secured. Therefore, dynamic compressive properties may be achieved at a wider range of strain rates by selecting the appropriate specimen diameter.

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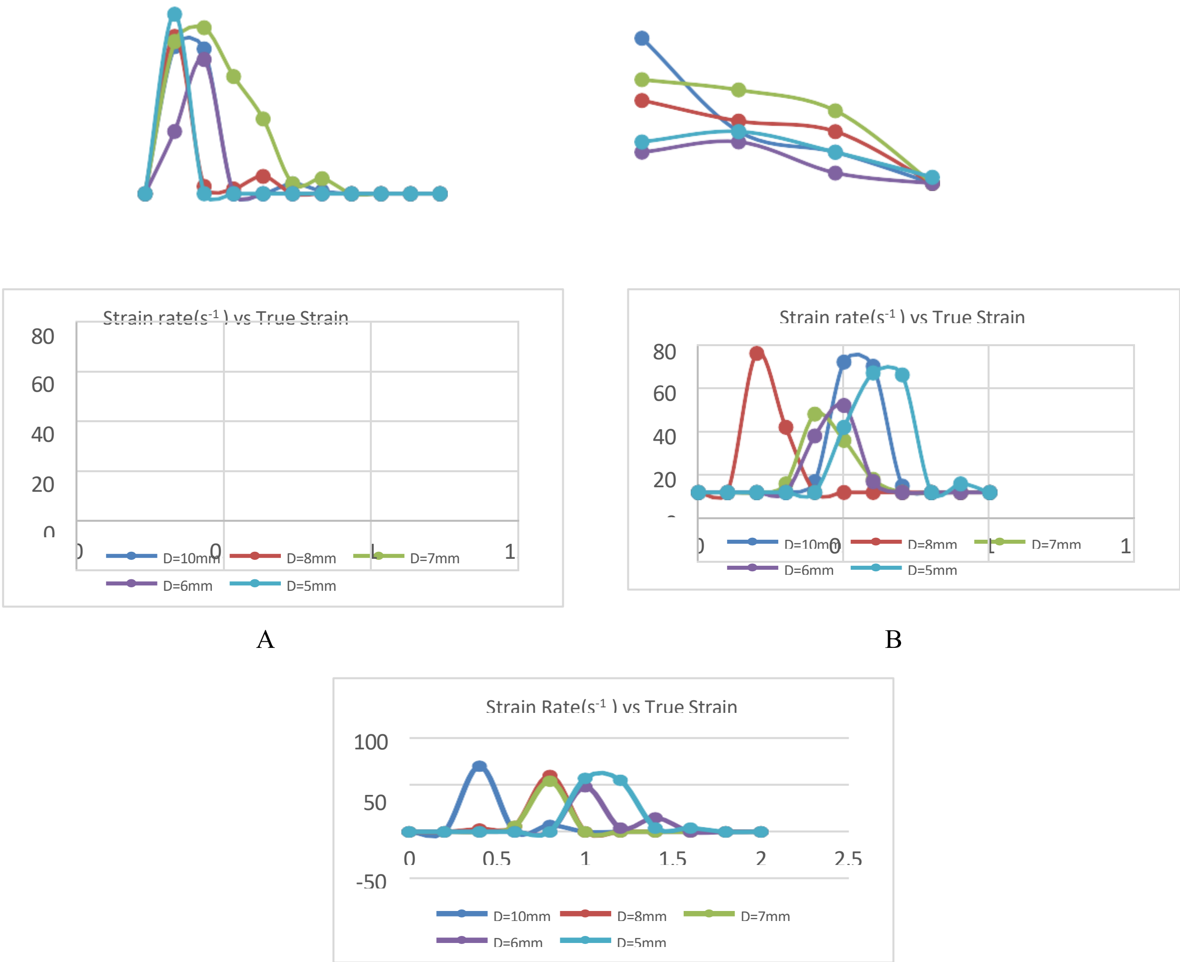
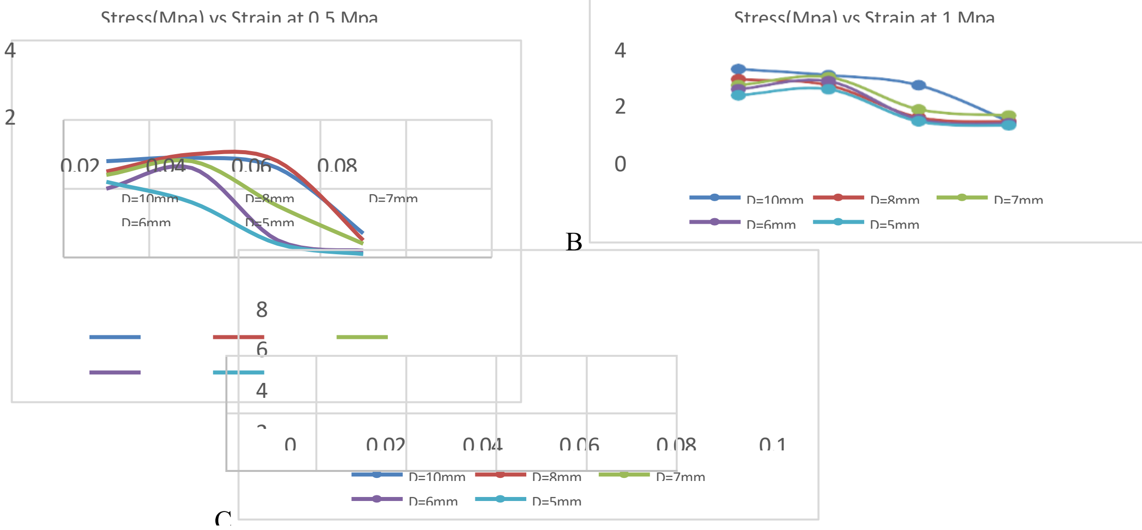


Figure 3.4: Results of studies showing strain rate–true strain curves for different diameters and pressures (a) 0.5, (b) 1.0, and (c) 1.5 bar.

Figure 3.4 depicts the stress-strain curve of AHSS under different impact loading as established by the SHPB tests. As we can see, the stress in the material rises initially and peaks at a modest strain rate before falling as the wave leaves the transmission end. The experiment is evaluated at air pressures between 0.5 and 1.5 Mpa in order to control and lock the air pressure at the start of the test using an air compressor valve.



0	2	4	6	8
0.	0.	0.	0.	0
0	0	0	0	.1

Figure 3.5: A comparison is made between the true stress–true strain curves for experimental values (a) 0.5, (b) 1.0, and (c) 1.5 bar.

The stresses and strain values when measured in structural static analysis done in ANSYS workbench 2024 R2 were also compared with the SHPB results. It clearly shows that the stress values increases with the increasing thickness of the specimen.

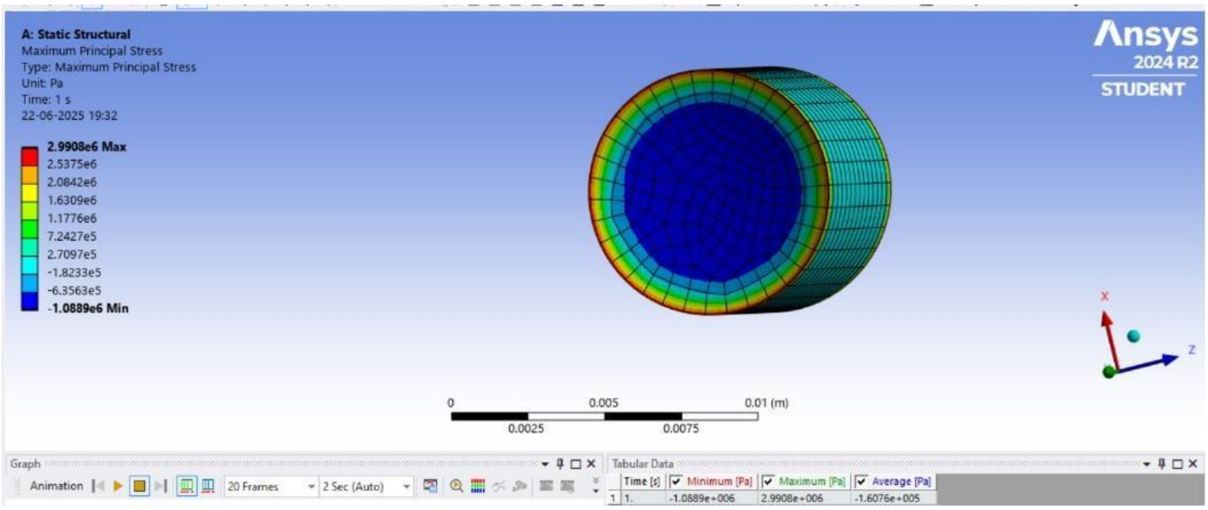
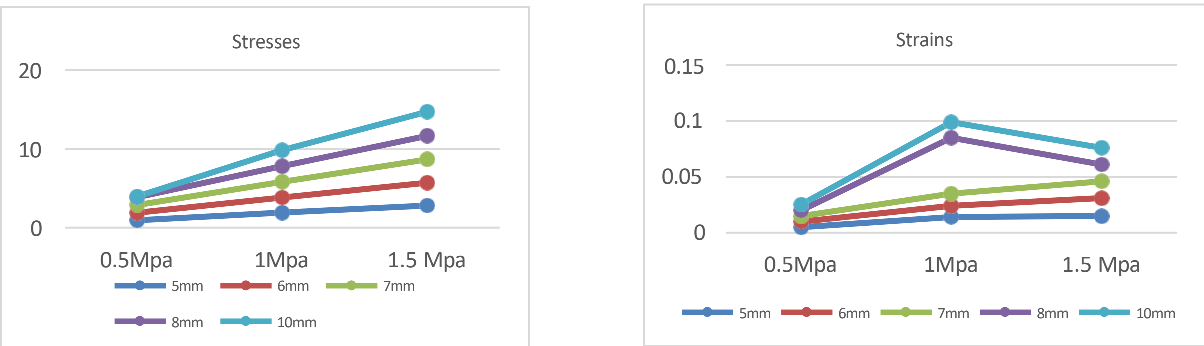


Figure 3.7: Representation static structural analysis of a 3D model of a specimen generated in ANSYS software



A B

Figure 3.8: Stresses and strain values in Ansys for pressure values of 0.5Mpa, 1 Mpa and 1.5 Mpa for specimens of 5mm, 6mm,7mm, 8mm and 10 mm.

Figure 6 and Figure 8 shows that as diameters increase, total stresses increase as well. The reason for this is that the specimen's cross-sectional area is more significant. Because of strain hardening, AHSS's yield strength and tensile strength increase with strain, which is beneficial for applications requiring a high load-bearing capacity.

4 Conclusion

In this work, AHSS material altering L/D ratios were used to perform dynamic compression tests on SHPB and structural static analysis is done in ANSYS 2024 R2. The S-S curves of the specimen were found to change as its diameter was altered. For rate-dependent elastic plastic materials, the L/D of the specimen has no significant effect on the stress level. As the slenderness ratio reduced, the specimen's stress decreased as well. The strain rate can be altered, and suitable S-S curves can be generated by altering the specimen diameter. Furthermore, Dynamic analysis can be done to understand the impact analysis of the specimen.

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