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High Strain Rate Compressive Behaviour of Additively Manufactured Nylon 12

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Abstract

The behaviour of polymers under high strain-rate loading conditions remains insufficiently understood than their quasi-static response, despite their benefits in producing lightweight structural components and rapid prototyping. The study aimed to determine the compressive behaviour of a 3D-printed polymer, Nylon 12, under high strain-rate conditions using a conventional Split Hopkinson Pressure Bar (SHPB) apparatus. Cylindrical specimens were 3D printed by varying printing orientation (flat/side and upright) and tested at impact velocities of 10 m/s, 15 m/s, and 20 m/s. Nylon 12 demonstrated strain-rate dependence, characterized by changes in yield stress and changes in failure mode. At lower strain rates, the material, in both printing orientations, showed ductile bulging, whereas in higher strain rates, the side printed material demonstrated a shift towards brittle failure. These failure modes were confirmed through High-Speed imaging. Results obtained from this study provide reliable high-strain rate material data for 3D printed Nylon 12, supporting improved prediction of the structural performance of Nylon 12 components under impact loading conditions.

Keywords
3D-printed, Printing Orientation, Nylon 12, Split Hopkinson Pressure Bar (SHPB) and Strain rate.

1. Introduction
Additive manufacturing (AM), specifically fused deposition modelling (FDM), has rapidly advanced as a favourable technique for manufacturing lightweight structural components, prototypes, and usable components across various industries such as aerospace, automotive, and defence (Mohamed etal 2015) (Lee etal 2017). Characteristics such as chemical resistance, good fatigue performance, dimensional stability, and high toughness have made Nylon 12 (polyamide 12) popular among the engineering polymers used in FDM (Torrado and Roberson 2016) (Berretta etal 2017).

The mechanical behaviour of 3D-printed polymers under high strain-rate loading conditions remains insufficiently understood despite their rapid use in functional applications. It is important to understand the rate-dependent behaviour of additively manufactured structural parts as they can be subjected to blast-type, crash, or impact loading conditions during their lifetime especially when used in military or mining applications. Polymers are generally viscoelastic and strain-rate sensitive. At higher strain rates, they often exhibit enhanced stiffness and strength (Wang 2021) (Vanaei 2022).

Split Hopkinson Pressure Bar (SHPB) testing is a well-established method for the characterisation of material behaviour at strain rates typical in the range of 10^2 s^{-1} to 10^4 s^{-1} (Nishida 2009). Few studies have investigated 3D-printed polymers, where printing orientation, interlayer bonding, and anisotropy greatly affect the mechanical response, although numerous studies have used SHPB testing to examine traditional or injection-moulded polymers

(Nishida 2009) (Isaac etal 2021) (Siviour and Jordan 2016). Published material datasheets from OEMS (original equipment manufacturer) like Stratasys focus on quasi-static loading rather than dynamic/transient loading conditions. In this study, 3D-printed Nylon 12 specimens were manufactured using a Stratasys Fortus 900mc, an industrial FDM printer that provides consistent part infill density and interlayer bonding, which enables repeatability and precise process control (Stratasys 2015) (Stratasys 2022). To evaluate the impact of printing orientation on mechanical behaviour under high strain-rate compression, cylindrical specimens were manufactured in the upright and flat/side orientations. The SHPB apparatus was used for testing at impact velocities of 10, 15, and 20 m/s to examine failure modes and strain-rate dependence of the material.

The outcomes of this study contribute to a broader knowledge of understanding of rate-dependent failure in 3D-printed polymers and provide experimental data for the calibration of computational constitutive models and the structural design of additive-manufactured parts that are subjected to transient/impact loading conditions.

1.1 Objectives

The primary objective of this study is to investigate the high strain rate compressive behavior of additively manufactured Nylon 12. The research aims to investigate how different printing orientations affect the material's mechanical properties under varying dynamic impact loading. The study aims to:

i. Quantify Strain rate dependence of Nylon 12.
ii. Assess the effects of printing orientation on the mechanical performance and failure modes under compressive loading.
iii. Generate high strain-rate data that can support computational modelling, design and prediction of Nylon 12 components subjected to transient or impact loading conditions.

2. Literature Review

Additive manufacturing (AM) technologies, especially fused deposition modelling (FDM), have become essential for manufacturing end-use polymer components due to their reduced production time, design flexibility, and material efficiency. Quasi-static tensile, flexural, and compression testing have been the main focus of research on the mechanical behaviour of 3D-printed polymers (Appalsamy et al. 2024) (Chacón et al. 2017). Mechanical strength and failure strain are greatly influenced by printing orientation, layer thickness, and infill density/pattern, according to studies conducted on polymer materials, namely Acrylonitrile-butadiene-styrene (ABS), Nylon, Polylactic acid (PLA), ASA, and Nylon 12 (Aloyaydi et al. 2020) (Afrose et al. 2016). The Split Hopkinson Pressure Bar testing method remains the most popular experimental method for studying material behaviour at high strain rates (10^2–10^4 s^{-1}) (Bergström and Boyce 1998).

A recent study by Dura et al. (2025) examined the strain-rate sensitivity of five different 3D-printed polymer materials, namely, ABS, PLA, Toughened PLA (TPLA), and Thermoplastic polyurethane (TPU). They found that high-strain-rate tests are complicated by the orthotropic properties and inherent defects of printed components. The authors demonstrated that for these AM-polymers, the yield strength and flow behaviour changed markedly with strain rate, and that build orientation and defect density had a measurable impact on dynamic performance. The study found that the "nylon" specimens exhibited positive strain-rate sensitivity, meaning their compressive yield stress increased with increasing strain rate.

Vidakis (2025) investigated the strain-rate sensitivity of two high-performance thermoplastics; polysulfone (PSU) and polyphenylsulfone (PPSU) manufactured through extrusion-based additive manufacturing. The study aimed to quantify the variation in mechanical properties of these materials with applied strain rate and to establish practical strain-rate sensitivity metrics for use in engineering design. Specimens were 3D-printed and subjected to tensile and compressive tests across multiple loading rates to capture changes in strength, stiffness, and failure behaviour. The results revealed that both polymers exhibited rate-dependent mechanical response, characterized by increasing yield and ultimate stresses with higher strain rates, accompanied by a reduction in ductility. This work highlights the broader importance of understanding strain-rate effects in additively manufactured high-performance polymers, complementing similar research on materials such as Nylon 12 and supporting the need for high strain-rate testing using methods like the Split Hopkinson Pressure Bar to develop reliable constitutive models for AM parts.

While the quasi-static mechanical behavior of 3D printed polymers is well established, there is a lack of experimental data describing their performance under high strain rate conditions. In particular, the dynamic response of FDM-printed Nylon 12 has not yet been extensively explored, especially combining the effects of printing orientation and strain rate. Existing studies, such as Smith et al. focused on other polyamides (Nylon 6) fabricated using a hobby-grade printer, thus limiting their applicability to industrial grade manufacturing environments. There is a limited understanding of how failure modes change under dynamic loading conditions, especially when using high-performance additive manufacturing systems such as the Stratasys Fortus 900mc. This research gap shows the need to investigate the high strain-rate compressive behaviour of Nylon 12 produced by 3D printing.

3. Methods

3.1 Material

The material used in this study is Nylon 12 (Polyamide 12) filament produced by Stratasys, used mostly in additive manufacturing of engineering components.

3.2 Specimen Fabrication

The compression specimens were fabricated using a Stratasys Fortus 900 mc industrial grade fused deposition modeling (FDM) printer. The 3D printer is a professional material extrusion (MEX) 3D printer and offers a dimensional accuracy of ± 0.09 mm. The specimen geometry was first modelled using Autodesk Inventor, after which the CAD model was exported to STL (Stereolithography) format and processed through Insight, the printer's slicing software. Printing was done using Stratasys Nylon 12 filament. The specimens were sliced using two print orientations: side print and upright orientation. This is primarily because 2 of the 3 primary axes are the same for the cylindrical compression specimen.

3.2.1 Printing Orientation

The specimens were printed in two different orientations based on the conventional Cartesian reference planes. Specimens printed on the ZX plane will be referred to as "upright", while those printed on the YZ plane will be called "side".

3.2.1 Infill Density

All specimens were fabricated with an infill density of 100%, to ensure no internal voids. The printing parameters including nozzle temperature and print speed were kept constant to maintain consistency between the upright and side printing orientations.

4. Data Collection

The dynamic compression tests were carried out using a conventional Split Hopkinson Pressure Bar (SHPB) apparatus as shown in Figure 1. 3D printed specimens were positioned between the incident and the transmitter bars. Upon impact by the striker bar, a compressive stress wave was generated and propagated through the incident bar towards the specimen and then the transmitter bar. Both the incident and transmitter bars were free to translate along the axial direction and were precisely aligned to ensure uniaxial loading.

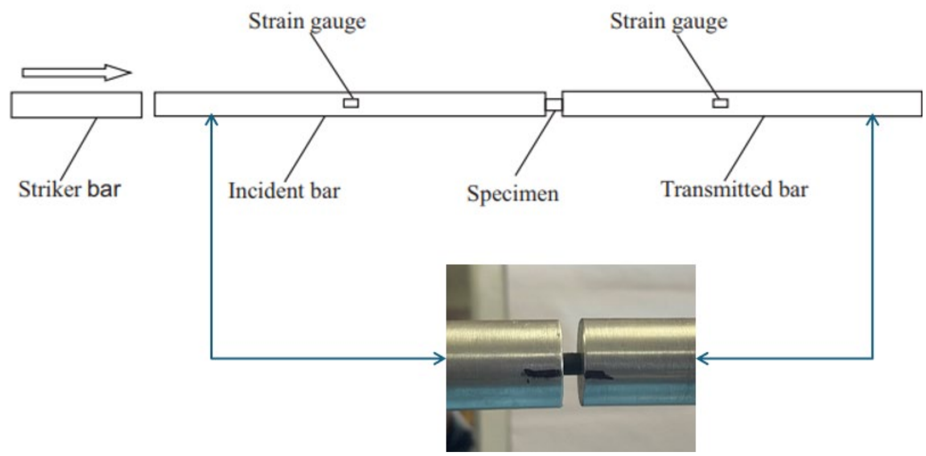

Figure 1. SHPB Setup Schematic Diagram

The SHPB used in this current study consisted of Aluminum 6082-T6 test bars. The bars were measured to be 2200 mm in length and 25 mm in diameter. A striker bar, 300 mm in length and 25 mm in diameter, was used to generate stress pulse. This type of Aluminum was used after conducting literature review to identify the most suitable material to characterize 3D printed polymers at high strain rates.

A thin layer of grease was applied to both ends of the specimens and the contacting faces of the incident and transmitter bars to minimize interfacial frictional effects during impact loading. To improve the quality of the stress wave signal by minimizing noise effects, a pulse shaper was used. The pulse shaper was used to modify the shape of the incident pulse, by smoothing the wavefront and eliminating high frequency oscillations that could distort the stress-strain data.

During testing, the striker bar is propelled by pressurized air from the gas gun toward the incident bar, producing a compressive stress pulse that propagated through the bar and into the specimen and the transmitter bar. The resulting incident reflected and transmitted strain waves were recorded using strain gauges mounted at the mid sections of both the incident and the transmitted bars. One 350 Ω strain gauge on each bar was used for precise measurement of the stress wave propagation. The strain signals were recorded using an HBM gen7t high-speed data acquisition system operating at a sampling rate of 1 MS/s (Mega samples per second). All the data recorded was processed to determine the stress-strain response of the specimens. Additionally, a velocity measurement system was used to record the initial impact velocity of the striker bar prior to contact with the incident bar, thus ensuring accurate determination of the strain rate and repeatability of the loading conditions.

5. Results and Discussion

The dynamic response of the specimen under this setup was analyzed based on one-dimensional elastic wave propagation theory. The time histories of the specimen stress $\boldsymbol{\sigma(t)}$, strain $\boldsymbol{\varepsilon(t)}$, and strain rate $\boldsymbol{\dot{\varepsilon}(t)}$ were evaluated using the 1-D theory. This approach relies on the simultaneous measurement of the incident and transmitted strain signals from the strain gauges mounted on the incident and transmitter bars. The governing equations are as follows:

$$\varepsilon(t) = \frac{C_b}{l_s}(\varepsilon_\iota - \varepsilon_r - \varepsilon_t)$$

$$\dot{\varepsilon}(t) = \frac{C_b}{l_s}\int_0^t (\varepsilon_i - \varepsilon_r - \varepsilon_t)dt$$

$$\sigma(t) = \frac{E_b A_b}{2A_s}(\varepsilon_i - \varepsilon_r - \varepsilon_t)$$

Where $\varepsilon_i, \varepsilon_r, \ \varepsilon_t$ are the incident, reflected and the transmitted strain pulses. C_b is the elastic wave velocity of sound in the test bars along the longitudinal axis. l_s is the length of the specimen. A_b is the cross-section area of the test bar. A_s is the cross-section area of the specimen, 'E' refers to the Young's Modulus of the bar material and 't' is the time duration of the test.

5.1 Numerical Results

Table 1 presents a summary of dynamic compression parameters for Nylon 12 specimens printed in upright and side orientations at different impact speeds. Each value represents the average of two / three tests conducted at similar test conditions. From the table, it can be noted that both the printing orientation and the impact velocity affect the dynamic compressive behavior of Nylon 12. The average strain rate increased with impact speed, ranging from 1800-2200 /s at 10 m/s to over 5000 /s at 20 m/s. The side printed specimens consistently outperformed the upright printed specimens; this was observed with higher calculated compressive strength across all strain rates.

Table 1. Summary of Dynamic Compression Results of 3D Printed Nylon 12 Specimens at Different Impact Velocities and Print Orientations

Impact Speed (m/s)	**10**		**15**		**20**	
Print orientation	Side	Upright	Side	Upright	Side	Upright
Average Strain rate (/s)	2206	1853	2892	2673	5267	4989
Average Peak Stress (MPa)	90,68	90,22	96,82	98,41	138,89	128,25
Average maximum strain	0,25	0,20	0,34	0,31	0,54	0,52

5.2 Graphical Results

Resulting engineering stress-strain curves for 3D printed Nylon 12 specimens obtained at different strain rates are shown in Figure 2 and Figure 3. All specimens showed an initial linear elastic region followed by strain hardening. The results show strain rate sensitivity of the material, where the yield stress decreases with increasing strain rate, and the peak stress increased with an increasing strain rate. This observation is different from typical polymers, where the yield and peak stress increase with an increasing strain rate (Y. Xu, et al. 2023). At different impact speeds, the curves show a similar overall trend. Printing orientation has a noticeable influence on the compressive mechanical behaviour of the material.

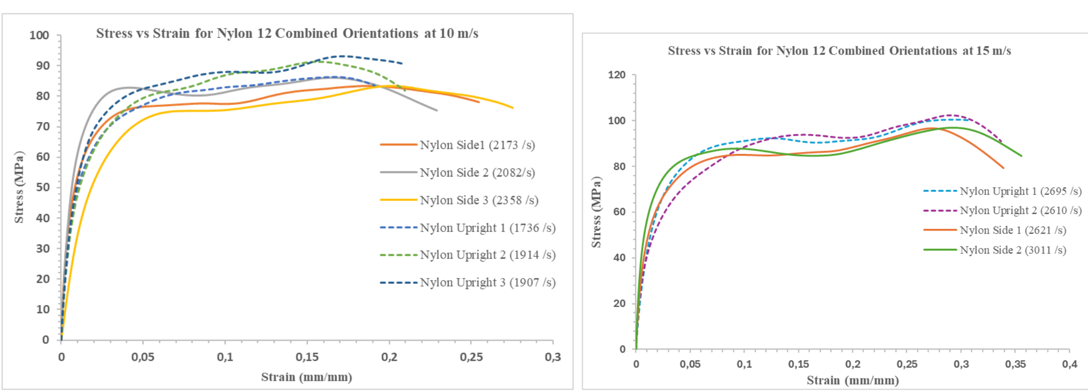

Figure 22. Stress vs Strain Curves for Nylon 12 Impacted at 10 m/s and 15 m/s

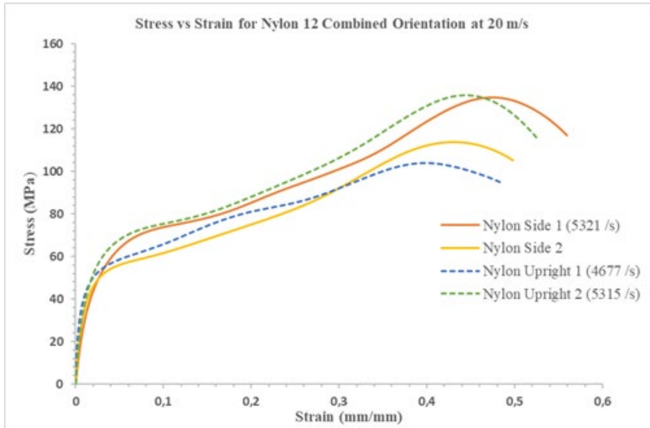

Figure 33. Stress vs Strain Curves for Nylon 12 Impacted at 20 m/s.

Nylon 12 shows strain rate sensitivity and this is evident by the varying in peak stresses at different strain rates. The material demonstrated a reduction in yield strength with an increasing loading rate, which contrasts with the typical behavior observed in most polymers. Under compressive strain rates between 1850 /s and 2890 /s, the predominant failure mode observed in Nylon 12 specimens was bulging, irrespective of the printing orientation. This deformation mode was accompanied by a noticeable reduction in the cross-sectional area of the specimens. At a higher compressive strain rate (4900 /s +), the side printed specimens exhibited a failure mode of fracture, this was characterized by a loss of load bearing capacity and the absence of significant plastic deformation. This change in failure mode of the specimen reflects the material's strain rate dependent on its mechanical response under high-speed impact loading conditions. As the strain rate increases, the material's energy absorption capacity increases, this is evident from an increased area under the stress-strain curves. Contrast to the peak stress, specimens printed in the side orientation exhibited lower energy absorption compared to the upright ones. Figure 4 and Figure 5 show the High-Speed video snapshots of upright and side printed specimens respectively. From these images it can be noted that the upright specimens are more ductile at higher strain-rates, and the side printed ones exhibit a brittle behavior.

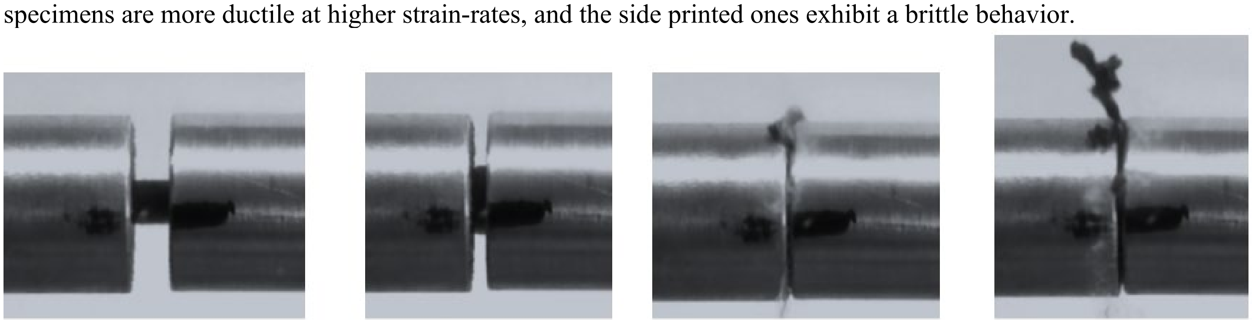

Figure 4. High Speed Camera Snapshots for Upright Printed Nylon 12 at 20 m/s

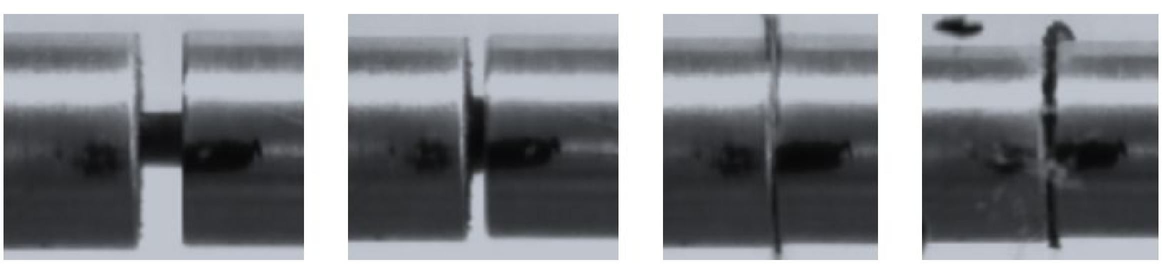

Figure 5. High Speed Camera Snapshots for Side Printed Nylon 12 at 20 m/s

5.3 Proposed Improvements

Although the current study successfully characterized high strain behavior of 3D printed Nylon 12, improvements are proposed to enhance the accuracy and reliability of future research:

- Computational Modeling and Simulation
  A finite element model of the SHPB setup should be developed to validate experimental results.
- Digital Image Correlation (DIC)
  Using DIC techniques to measure strain will enable validation of strain gauge results.

5.4 Validation

Prior to data reduction, the validity of the experimental results was confirmed by assessing the dynamic stress equilibrium within the specimen. This was achieved by comparing the sum of the incident and reflected pulses with the transmitted pulse at the specimen–bar interfaces. When these two waveforms are in close agreement in both shape and amplitude, the specimen can be in dynamic equilibrium, ensuring that the measured stress and strain data accurately represent its true material response. To minimize test variability, three identical specimens were tested under the same launch pressure (same impact speed), resulting in similar strain rates. The corresponding stress–strain curves were averaged to obtain a representative curve for each strain rate condition**.**

6. Conclusion

This study investigated the influence of printing orientation and strain rate dependance of 3D printed Nylon 12 using the SHPB. Cylindrical specimens were fabricated inside and upright printing orientations with 100% infill density to ensure consistency in the material structure. The results showed that Nylon 12 is a strain rate dependent material, with both peak stress and strain at failure increasing with an increase in strain rate. Printing orientation was also found to affect the mechanical behaviour of the material. Side printed specimens consistently demonstrated higher peak stress and overall improved load-bearing capacity. The upright printed specimens showed a greater strain-rate dependence, especially in their deformation behaviour.

Failure modes were influenced by strain rates. At lower strain rates, specimens exhibited ductile bulging, at higher strain rates the material transitioned to brittle fracture, thus indicating a rate-dependent change in deformation. Overall, the findings meet the study's objectives by quantifying the effects of strain rate and printing orientation on dynamic compressive behavior of Nylon 12. The results provide guidance for optimizing printing orientation and design parameters when Nylon 12 is used in structural components subjected to impact / transient loading conditions.

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