White paper

ESTANE® 3D TPU M95A for the HP Jet Fusion 4200 3D Printing Solution

Mechanical Properties

Introduction

At HP, we are committed to providing part designers and part manufacturers with the technical information and resources needed to enable them to unlock the full potential of 3D printing and prepare them for the future era of digital manufacturing.

The aim of this white paper is to illustrate the mechanical properties of HP 3D Printing materials that can be achieved with the HP Jet Fusion 4200 3D Printing Solution.

In this white paper, you will find:

- Key mechanical properties for for ESTANE® 3D TPU M95A[1],
- A detailed explanation of the test conditions under which these values were obtained, and
- Additional information on the mechanical properties of thermoplastic materials, and a glossary of key terms used.

Material properties for ESTANE® 3D TPU M95A

Test job

The baseline material properties for parts produced with ESTANE® 3D TPU M95A with the HP Jet Fusion 4200 3D Printing Solution were characterized using a test job, *Half bucket part property test build* (Figure 1), to evaluate part properties and material performance. Parts were selected for mechanical, dimensional, and look-and-feel qualitative evaluation.

The printable volume was packed with a packing density of 6.89% and had a total of 134 total parts with a minimum part spacing of 6 mm. Parts were distributed throughout the printable volume in a manner where center/edge or top/bottom signals could be found. In addition, many parts were tested in multiple orientations (e.g., XY or Z). The part property test results section shows results from multiple powder generations.

The configuration of the job is shown in Figure 1.

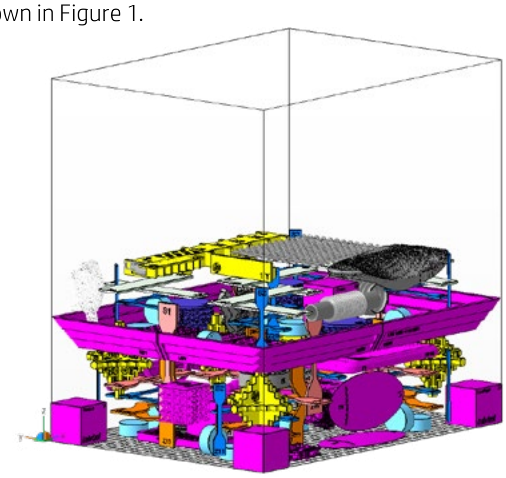

Figure 1. Half bucket part property test build. Parts are color-coded by mechanical (orange/blue), dimensional (orange), and look and feel (purple/grey).

Test job description	Half bucket part property test build
Total parts	134
Time to print	12 hours
Time to cool (Natural cooling)	22 hours
Packing density	6.89%

Table 1. General description of the test job

1. Available for the HP Jet Fusion 4200 Series 3D Printing Solution.

Several test specimens to evaluate tensile strength, abrasion, rebound, compression set, and tear strength were distributed throughout the test bed (Figure 2). An application lattice test part (purple), which is described in the ESTANE® 3D TPU M95A technical data sheet (TDS), was included and tested for vertical resilience, swing-arm resilience, and compression set.

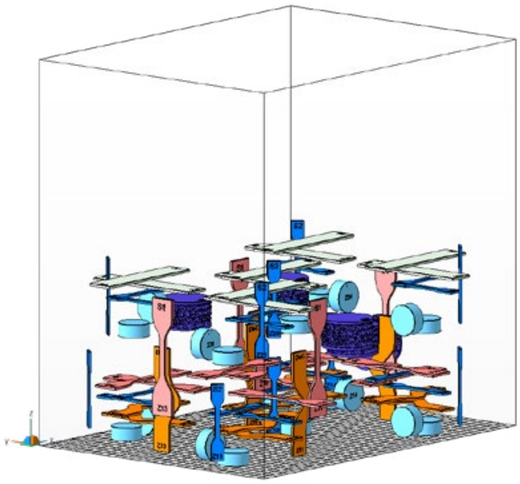

Figure 2. View of mechanical parts in the Half bucket part property test build. Other parts are hidden to more clearly show the part locations.

	Number of samples	
	XY	Z
S2 tensile sample	20	10
S1 tensile sample	10	5
Abrasion / Compression / Rebound	10	10
Tear specimen	10	5
Ross flex	10	
Application lattice	4	1

Table 2. Number of samples used in the test job

Test results

A characterization of mechanical part properties for ESTANE® 3D TPU M95A was obtained based on the aforementioned part property test job.

Tests were based on a single print volume configuration; therefore, the results may vary as part design and print volume configuration change. All testing was performed with a new-to-recycled powder mix ratio of 20:80.

Several mechanical properties were tested in half jobs across several generations, and their respective degradation profile was characterized (Table 3).

In all results up to generation 11, degradation in all properties is expected and higher degradation is observed in Z-oriented parts. Degradation values are much higher in full buckets; therefore, half buckets are recommended.

ESTANE® 3D TPU M95A[i ii iii]	XY (Gen 1)	XY % degradation from Gen 1 to Gen 11	Z (Gen1)	Z % degradation from Gen 1 to Gen 11	Test method
Tensile strength (MPa)	16	18%	7	26%	DIN-53504/ISO-37
Elongation at break (%)	370	17%	90	38%	DIN-53504/ISO-37
Tear strength (N/mm) [Die C]	109	16%	53	28%	ASTM D624
Hardness (5 sec) [Shore A]	90	N/A	90	N/A	ASTM D2240
Abrasion volume loss (mm^3)	92	19%	80	26%	DIN-53516/ISO-4649

i. Based on internal testing and measured using the Half bucket part property test build. Results may vary with other jobs and geometries.

ii. Using ESTANE® 3D TPU M95A material, 20% refresh ratio, Balanced print profile, natural cooling, and measured after bead-blasting with glass beads at 5-6 bars.

iii. Following all HP-recommended printer setup and adjustment processes and printheads aligned using semi-automatic procedure.

Table 3. Mechanical test results from half bucket test build printed at 6.89%

Some properties such as tensile strength, elongation at break, and tear resistance are anisotropic in XY versus Z. Other properties are more isotropic, but it ultimately depends on the test specimen geometry. Long, thin parts will be more anisotropic, whereas larger parts will be more isotropic. As a result, long, thin parts should be printed in XY wherever possible to maximize mechanical strength.

A common design used with 3D printed elastomers is a lattice structure, which inherently contains long, thin struts within the lattice design. Lattice strength fares much better since the long, thin features are more tightly packed compared with printing separate long, thin parts. Based on this effect, long, thin parts such as Z dog-bone tensile samples can see improved mechanical performance by caging. Caging also helps facilitate the unpacking of smaller, fragile parts, and is a good technique for small parts where possible.

Appendix 1: Choosing the right material for mechanical requirements

One of the most critical aspects to understand before choosing a material is the stresses the part will experience in its regular operation mode. The chosen material must meet the application's requirements in terms of behavior under stress and provide a suitable yield point in order not to impact the part's functionality. Loads, boundary conditions, and design space for the part are usually given parameters, which cannot be modified. In some other cases where the loads may vary due to a dynamic situation, other factors and calculations should be considered to ensure, for instance, that the part withstand fatigue.

Ideally, designers should choose the material based on the application's specific requirements. However, performing the final selection is not easy, as often not all of the requirements for the application are known and, even if they are, there may not be a clear correlation between these final application requirements and the generic material properties (characterized by the standard procedures) or the variations the materials may have depending on the environment and conditions in which they operate. To simplify this choice, the commonly used process for material selection involves three steps:

STEP 1: Select a material with generic properties according to key attributes. In thermoplastics, the most commonly used properties are tensile strength, tensile modulus, and elongation, (but others may also be considered).

- Tensile strength measures the resistance of the material to breaking under tension.
- Tensile modulus measures the rigidity or resistance to elastic deformation.

Elongation measures the deformation (elastic or plastic) that a part undergoes given a certain strain.

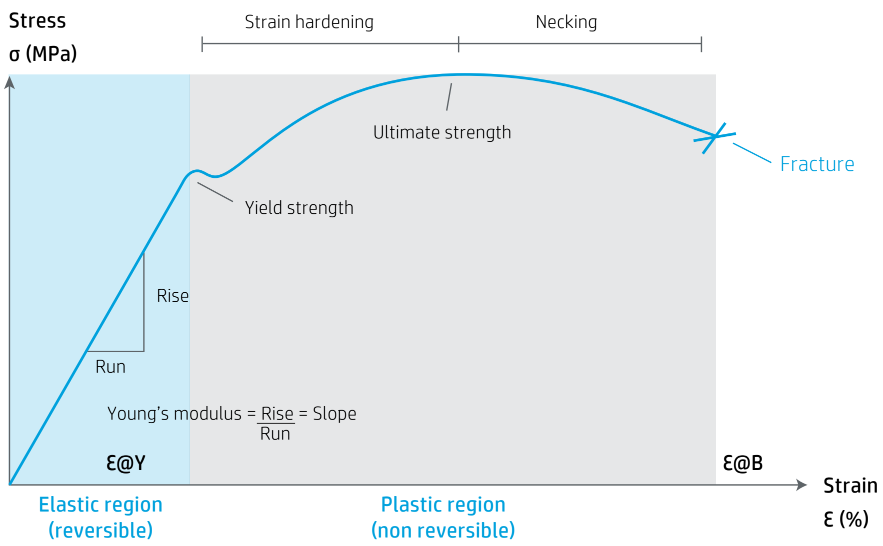

Figure 3. A typical stress-strain curve for a ductile material

These properties and the relative behavior of polymers compared to other materials are shown in Figure 3.

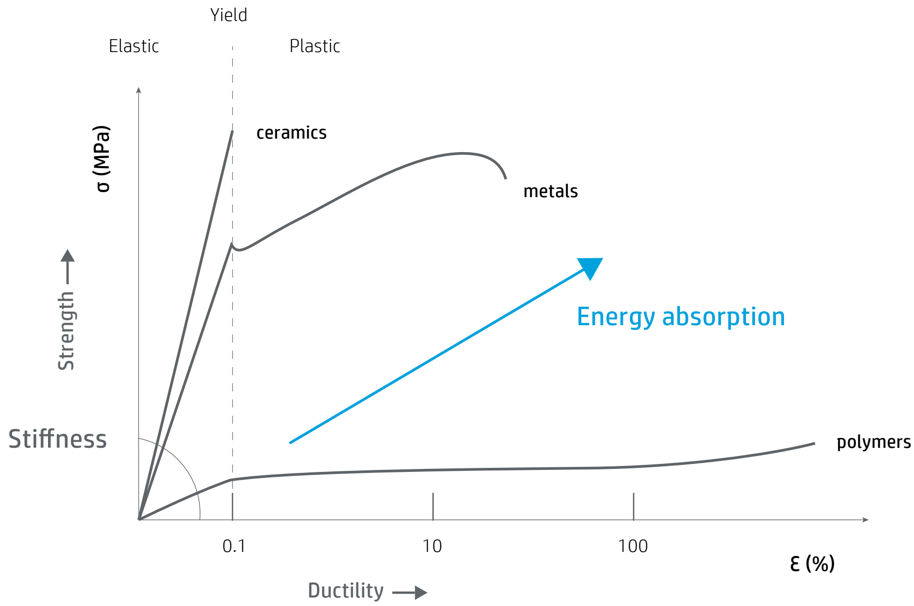

Figure 4. Comparison of polymer, metal, and ceramic materials

STEP 2: Once a material has been selected, the design of the part needs to be performed in line with HP Multi Jet Fusion design guidelines, allowing enough of a design margin (two or three times, depending on the property) to accommodate for all possible variations in the part itself or in the application-specific conditions.

STEP 3: Even after the design has been performed according to these principles, it is highly advisable to conduct a full application-specific qualification to ensure the precision of the design, obtain validation data that represent the application's end-to-end performance, and characterize its variation over time or according to other production and application variation factors.

Appendix 2: Key terms

- **Tensile strength** or Ultimate Tensile Strength (UTS) is typically measured in MPa or N/mm^2. It is the capacity of a material to withstand tension loads. Tensile strength is measured by the maximum stress that a material can withstand while being pulled before breaking.
- **Tensile modulus** (also Young's Modulus or E) is typically measured in MPa or N/mm^2. It is a mechanical property that measures the stiffness of a solid material. It defines the relationship between stress and strain in a material in the linear elasticity regime. Since thermoplastics have a very short linear elasticity zone, it is calculated as the slope of the stress-strain curve very close to zero. Tensile modulus is required as an input for mechanical FEA simulations
- **Elongation** measures the deformation that a part undergoes given a certain stress. For thermoplastics, it is typically expressed as a percentage (%) of the deformed amount versus the original part length.

  Elongation at yield in thermoplastics is the deformation corresponding to the tensile strength point, so where the stress-strain curve reaches its maximum.

  Elongation at break is the deformation corresponding to the fracture point of the part.
- **Abrasion volume loss** measures the ability of a material to resist abrasive wear. The abrasion loss is given as the volume loss in cubic millimeters.
- **Tear resistance** or tear strength is defined as the resistance force that a material sample, modified by cutting or slitting, offers to the propagation of the tear.
- **Hardness [Shore A]** is a specific test to determine the relative hardness of soft materials, usually plastic or rubber. The test measures the penetration of a specified indentor into the material under specified conditions of force and time. The hardness value is often used to identify or specify a particular hardness of elastomers.
- **Stress** is the force density (quotient of internal force and effective area) prevailing in every area element. There are two types of stresses depending on their direction to the cross-sectional plane studied: normal stress and shear stress.
- **Deformation** refers to any stress on a solid body that generates strain. A distinction is made between elastic and plastic deformation. Elastic deformations disappear once the imposed external load has been removed. Plastic deformations occur when the inner stresses exceed a certain limit that is intrinsic to the material. In this case deformations will remain after removal of the external load. Hence, plastic deformation is permanent and non-reversible.

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