White paper

HP 3D Printing materials for the HP Jet Fusion 5200 Series 3D Printing Solution

Mechanical properties

Data courtesy of ETSEIB MOTORSPORT

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 5200 Series 3D Printing Solution.

In this white paper, you will find:

- Key mechanical properties for HP 3D High Reusability (HR)[i] PA 12, enabled by Evonik, HP 3D High Reusability (HR)[ii] PA 12 S, enabled by Arkema, HP 3D High Reusability (HR)[iii] PA 11, HP 3D High Reusability (HR)[iv] PA 12 Glass Beads (GB), and HP 3D High Reusability (HR)[v] PP, enabled by BASF.
- A detailed explanation of the test conditions under which these values were obtained.
- Additional information on the mechanical properties of thermoplastic materials, and a glossary of key terms used.

Material properties for HP 3D Printing materials

Test job for material characterization

The baseline mechanical properties of each print profile and material of the HP Jet Fusion 5200 Series 3D Printing Solution were characterized using a standard job "Half_Commercial_Datasheet_Job". The job contained 349 diagnostic parts that were distributed throughout the printable volume.

The configuration of the job is shown in Figure 1.

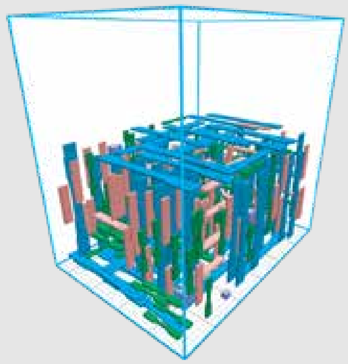

Figure 1. "Half_Commercial_Datasheet_Job" part property test job

Test job description	Half_Commercial_Datasheet_Job
Total parts	349
Packing density	6%

Table 1. General description of the test job

i. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability PA 12, enabled by Evonik provide up to 80% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical properties and accuracy.
ii. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability PA 12 S, enabled by Arkema, provide up to 85% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical properties and accuracy.
iii. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability PA 11 provide up to 70% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical properties and accuracies.
iv. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability PA 12 Glass Beads provide up to 70% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical properties and accuracy.
v. HP Jet Fusion 3D Printing Solutions using HP 3D High Reusability PP enabled by BASF provide up to 90% powder reusability ratio, producing functional parts batch after batch. For testing, material is aged in real printing conditions and powder is tracked by generations (worst case for reusability). Parts are then made from each generation and tested for mechanical.

The 'Half_Commercial_Datasheet_Job' part property test job included three different types of standard tensile specimens that allowed different metrics in X, Y, and Z orientations to be measured, where the X axis is the printheads direction, the Y axis is the recoating direction, and the Z axis is the vertical printer direction.

	Number of samples		
	XY	YX	ZX
Tensile sample I	22	20	42
Tensile sample V	30	30	70
Impact Izod 3.2 mm	30	30	60
Density cubes	15 (2 sizes)		

Table 2. Number of samples included in the "Half_Commercial_Datasheet_Job" test job

Test results for HP 3D HR PA12 S, enabled by Arkema

Table 3 shows the values that were obtained for HP 3D HR PA 12 S, enabled by Arkema in the HP Jet Fusion 5200 Series 3D Printing Solution with the Balanced PA 12 S print profile and Type I tensile specimens, following the ASTM D638 standard.

HP 3D HR PA12 S, enabled by Arkema[i, ii, iii]	Average (XY)	Average Z	Test Method
Tensile strength (MPa)[iv]	45	43	ASTM D638
Tensile modulus (MPa)[iv]	1700	1700	ASTM D638
Elongation at yield (%)	10	5	ASTM D638
Elongation at break (%)	12	5	ASTM D638
Impact strength (kJ/m²)[v]	2.5	2	ASTM D256
Density (g/cm³)	0.98		ASTM D792

i. Based on internal testing and measured using the "HP Half_Commercial_Datasheet_Job". Results may vary with other jobs and geometries.
ii. Using HP 3D HR PA 12 S, enabled by Arkema material, 15% 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.
iv. Tensile strength typical variation (95% of parts) falls within the 40-48 MPa range, while tensile modulus values remain within the 1500 to 1900 MPa range.
v. Using the Izod test method A with notched @ 3.2 mm specimen according to the ASTM D256 standard.

Table 3. Results for HP HR PA 12 S, enabled by Arkema

Test results for HP 3D HR PA 12, enabled by Evonik (Balanced PA 12 print mode)

Table 4 shows the values that were obtained for HP 3D HR PA 12, enabled by Evonik in the HP Jet Fusion 5200 Series 3D Printing Solution with the Balanced PA 12 print profile and Type I tensile specimens, following the ASTM D638 standard.

HP 3D HR PA 12, enabled by Evonik[i, ii, iii]	Average (XY)	Average Z	Test Method
Tensile strength (MPa)[iv]	50	50	ASTM D638
Tensile modulus (MPa)[iv]	1900	1900	ASTM D638
Elongation at yield (%)	10	8	ASTM D638
Elongation at break (%)	17	9	ASTM D638
Impact strength (kJ/m²)[v]	4.2	3.8	ASTM D256
Density (g/cm³)	1.01		ASTM D792

i. Based on internal testing and measured using the "HP Half_Commercial_Datasheet_Job". Results may vary with other jobs and geometries.
ii. Using HP 3D HR PA 12, enabled by Evonik 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.
iv. Tensile strength typical variation (95% of parts) falls within the 45-55 MPa range, while tensile modulus values remain within the 1650 to 2200 MPa range.
v. Using the Izod test method A with notched @ 3.2 mm specimen according to the ASTM D256 standard.

Table 4. Results for HP 3D HR PA 12, enabled by Evonik

Test results for HP 3D HR PA 12, enabled by Evonik (Robust PA 12 print mode)

Table 5 shows the values that were obtained for HP 3D HR PA 12, enabled by Evonik in the HP Jet Fusion 5200 Series 3D Printing Solution with the Robust PA 12 print profile and Type I tensile specimens, following the ASTM D638 standard.

HP 3D HR PA12, enabled by Evonik[i, ii, iii]	Average (XY)	Average Z	Test Method
Tensile strength (Mpa)[iv]	54	52	ASTM D638
Tensile modulus (Mpa)[iv]	2000	2000	ASTM D638
Elongation at yield (%)	10	9	ASTM D638
Elongation at break (%)	17	10	ASTM D638
Impact strength (kJ/m²)[v]	4.2	4.2	ASTM D256
Density (g/cm³)	1.01		ASTM D793

i. Based on internal testing and measured using the "HP Half_Commercial_Datasheet_Job". Results may vary with other jobs and geometries.

ii. Using HP 3D HR PA 12, enabled by Evonik material, 20% refresh ratio, Robust 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.

iv. Tensile strength typical variation (95% of parts) falls within the 45-55 MPa range, while tensile modulus values remain within the 1650 to 2200 MPa range.

v. Using the Izod test method A with notched @ 3.2 mm specimen according to the ASTM D256 standard.

Table 5. Results for HP 3D HR PA 12, enabled by Evonik

Test results for HP 3D HR PA 11

Table 6 shows the values that were obtained for HP 3D HR PA 11 in the HP Jet Fusion 5200 Series 3D Printing Solution, with PA 11 Balanced print profile and Type I tensile specimens, following the ASTM D638 standard.

HP 3D HR PA 11[i, ii, iii]	Average (XY)	Average Z	Test Method
Tensile strength (MPa)[iv]	54	54	ASTM D638
Tensile modulus (MPa)[iv]	1700	1800	ASTM D638
Elongation at yield (%)	25	20	ASTM D638
Elongation at break (%)	40	25	ASTM D638
Impact strength (kJ/m²)[v]	7.0	4.5	ASTM D256
Density (g/cm³)	1.05		ASTM D792

i. Based on internal testing and measured using the "HP Half_Commercial_Datasheet_Job". Results may vary with other jobs and geometries.

ii. Using HP 3D HR PA 11 material, 30% 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.

iv. Tensile strength typical variation (95% of parts) falls within the 50-58 MPa range, while tensile modulus values remain within the 1500 to 2200 MPa range.

v. Using the Izod test method A with notched @ 3.2 mm specimen according to the ASTM D256 standard.

Table 6. Results for HP 3D HR PA 11

Test results for HP 3D HR PA 12 GB

Table 7 shows the values that were obtained for HP 3D HR PA 12 GB in the HP Jet Fusion 5200 Series 3D Printing Solution, with PA 12 GB Balanced print profile and Type I tensile specimens, following the ASTM D638 standard. In this case, heat deflection temperature was characterized in a separate job configured for this purpose using a standard bar specimen according to the ASTM D648 standard.

HP 3D HR PA 12 GB[i, ii, iii]	Average (XY)	Average Z	Test Method
Tensile strength (MPa)[iv, v]	31	30	ASTM D638
Tensile modulus (MPa)[iv, v]	2900	3000	ASTM D638
Heat deflection temperature [@ 0.45 MPa, 66 psi] (°C)[vii]	170	172	ASTM D648
Heat deflection temperature [@ 1.82 MPa, 264 psi] (°C)[vii]	113	118	ASTM D648
Elongation at yield (%)[v]	8	4	ASTM D638
Elongation at break (%)[v]	9	5	ASTM D638
Impact strength (kJ/m²)[vi]	3	3	ASTM D256
Density (g/cm³)	1.3		ASTM D792

i. Based on internal testing and measured using the "HP Half_Commercial_Datasheet_Job". Results may vary with other jobs and geometries.
ii. Using HP 3D HR PA 12 GB material, 30% 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.
iv. Tensile strength typical variation (95% of parts) falls within the 28-32 MPa range, while tensile modulus values remain within the 2600 to 3200 MPa range.
v. Tensile test type I specimens measured with a pulling speed of 5 mm/min to comply with ASTM D638 test standards.
vi. Using the Izod test method A with notched @ 3.2 mm specimen according to the ASTM D256 standard.
vii. Using a standard bar specimen measuring 5" x ½" x ¼" in accordance with ASTM D648.

Table 7. Results for HP 3D HR PA 12 GB

Test results for HP 3D HR PP, enabled by BASF

Table 8 shows the values that were obtained for HP 3D HR PP, enabled by BASF in the HP Jet Fusion 5200 Series 3D Printing Solution, with PP Balanced print profile and Type I tensile specimens, following the ASTM D638 standard. In this case, heat deflection temperature was characterized in a separate job configured for this purpose using a standard bar specimen according to the ASTM D648 standard.[i, ii, iii]

	Average (XY)	Average Z	Test Method
Tensile strength (MPa)[iv, v]	29	29	ASTM D638
Tensile modulus (MPa)[iv, v]	1600	1600	ASTM D638
Heat deflection temperature [@ 0.45 MPa, 66 psi] (°C)[vii]	100	100	ASTM D648
Heat deflection temperature [@ 1.82 MPa, 264 psi] (°C)[vii]	60	60	ASTM D648
Elongation at yield (%)[v]	9.5	9.5	ASTM D638
Elongation at break (%)[v]	20	14	ASTM D638
Impact strength (kJ/m²)[vi]	3.5	3.0	ASTM D256
Density (g/cm³)	0.87		ASTM D792

i. Based on internal testing and measured using the "HP Half_Commercial_Datasheet_Job". Results may vary with other jobs and geometries.
ii. Using HP 3D HR PP, enabled by BASF material, 20% refresh ratio, Balanced print profile, natural cooling, and measured after bead-blasting with glass beads (70–110 µm) at 5-6 bars.
iii. Following all HP-recommended printer setup and adjustment processes and printheads aligned using semi-automatic procedure.
iv. Tensile strength typical variation (95% of parts) falls within the 27–31 MPa range, while tensile modulus values remain within the 1400–1900 Mpa range.
v. Tensile test type I specimens measured with a pulling speed of 5 mm/min to comply with ASTM D638 test standards.
vi. Using the Izod test method A with notched @ 3.2 mm specimen according to the ASTM D256 standard.
vii. Using a standard bar specimen measuring 5" x ½" x ¼" in accordance with ASTM D648.

Table 8. Results for HP 3D HR PP, enabled by BASF

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.

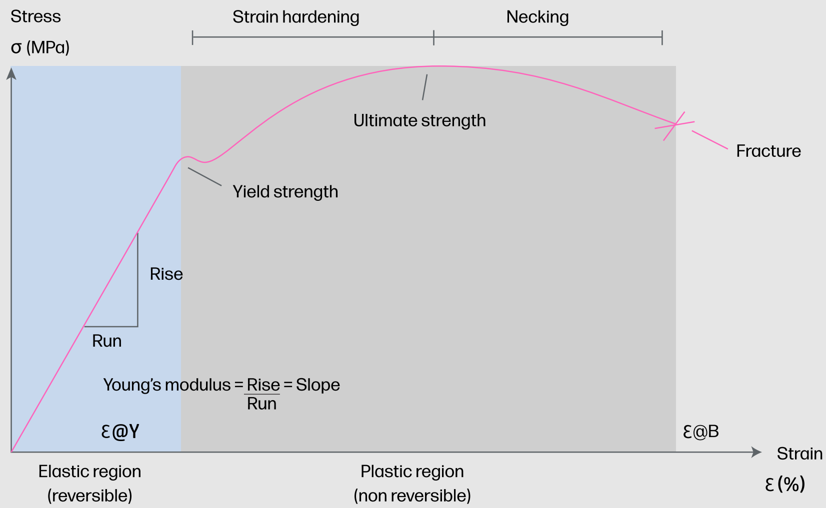

Figure 2. A typical stress-strain curve for a ductile material

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

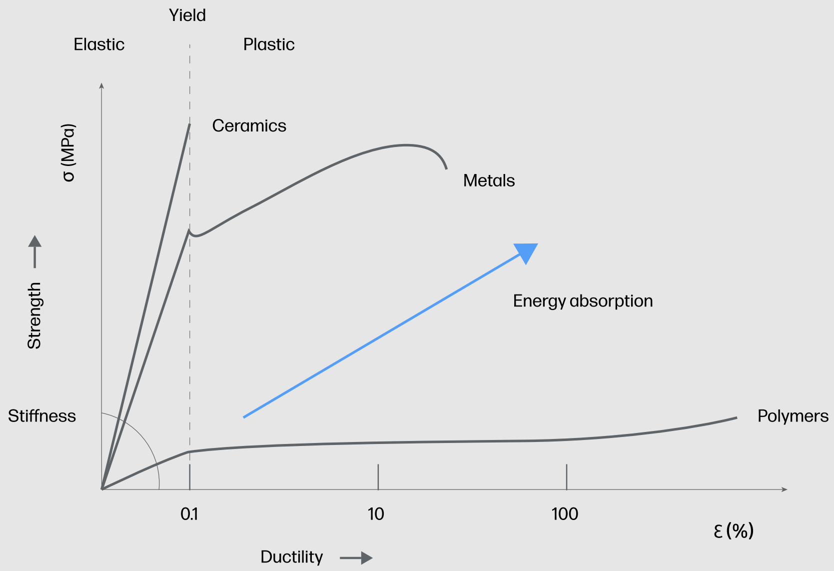

Figure 3. Comparison of polymer, metal, and ceramic materials

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.

- Impact strength measures the impact resistance of a material or the amount of energy absorbed by a material during fracture associated with its toughness. The units are typically kJ/m^2 (energy per unit area). There are two standard methods to measure impact strength: the Izod and the Charpy. Notched and unnotched specimens are used on the specific pendulum testers to determine the impact strength and the notch sensitivity.

- 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 nonreversible.

- Heat deflection temperature is defined as the temperature at which a standard test bar deflects a specified distance under a load. It is used to determine short-term heat resistance. It is determined at different loads, for example, 1.8 MPa (264 psi), which helps to determine maximum service temperature of parts, and 0.46 MPa, which provides an estimate of the service temperature a given polymer can withstand. Other settings like speed of the temperature increase or even part design will significantly influence the final thermal performance of an application.

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