Influencing factors of removability of support structures using high-frequency vibration

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Motivation

Fig. 1: State of the art support structure removal processes

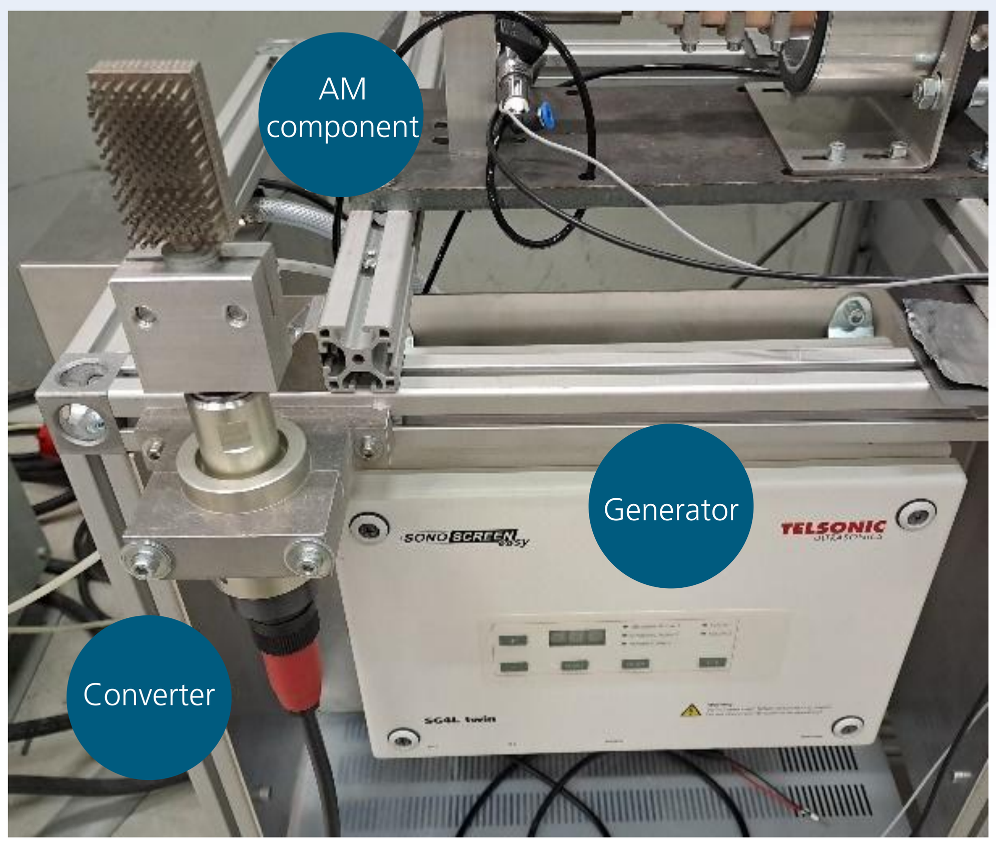
Current solutions present the following barriers to adaptation for companies:

- Handling of safety-critical substances
- High energy and resource requirements
- Restrictions in application and practical implementation
- High safety requirements for employees
- High lead times by high costs per part
- Low potential of adaptation of industrial companies

Methodology

Investigation of support structure behavior by inducing vibrations

- AM-printed test specimen made of Inconel 718 with PBF-LB/M
- Different types of support structure geometries (SM/DM) were investigated
- 33-37 kHz system (Telsonic) with an amplitude of approx. 1-3 µm



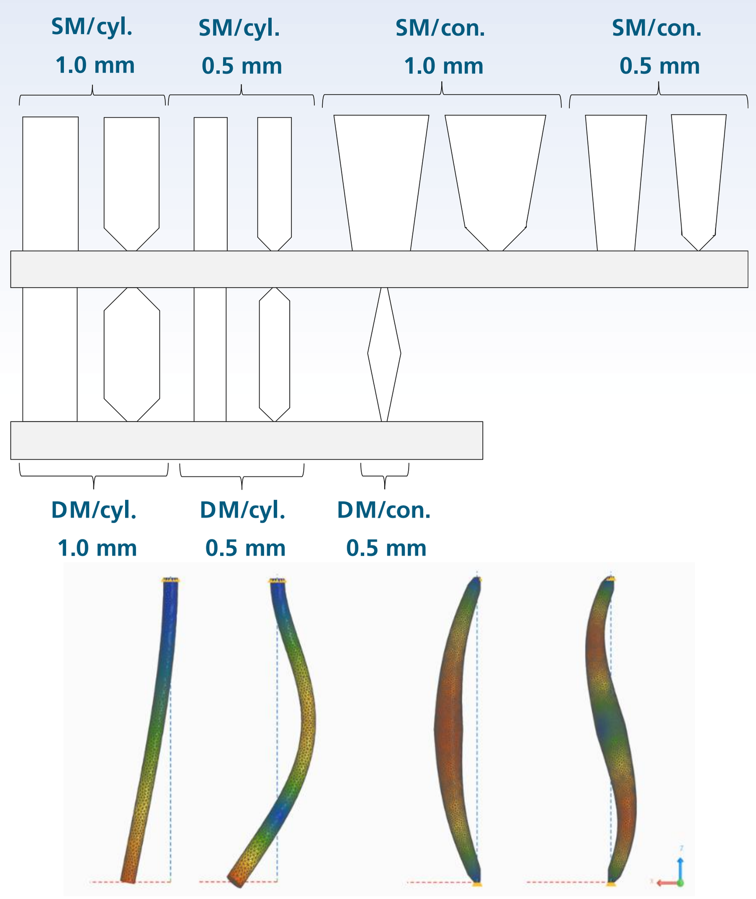


Fig. 2: Experimental setup (left); Visualisation of the support structure geometries that were investigated (top right); First and second modal form of single- and double-mounted supports (bottom right)

What are the main influencing factors for a reliable support structure removal using vibration?

Vibration transmission

- Increased temperatures were identified at the clamping geometry. Heat generation indicates a loss of energy (especially at screw- and clamping connection)
- Targeted **transmission of vibrations** by an amplitude transformation unit (sonotrode boosting adapter) is essential
- **Rigid oscillation system** with **directional oscillation** required

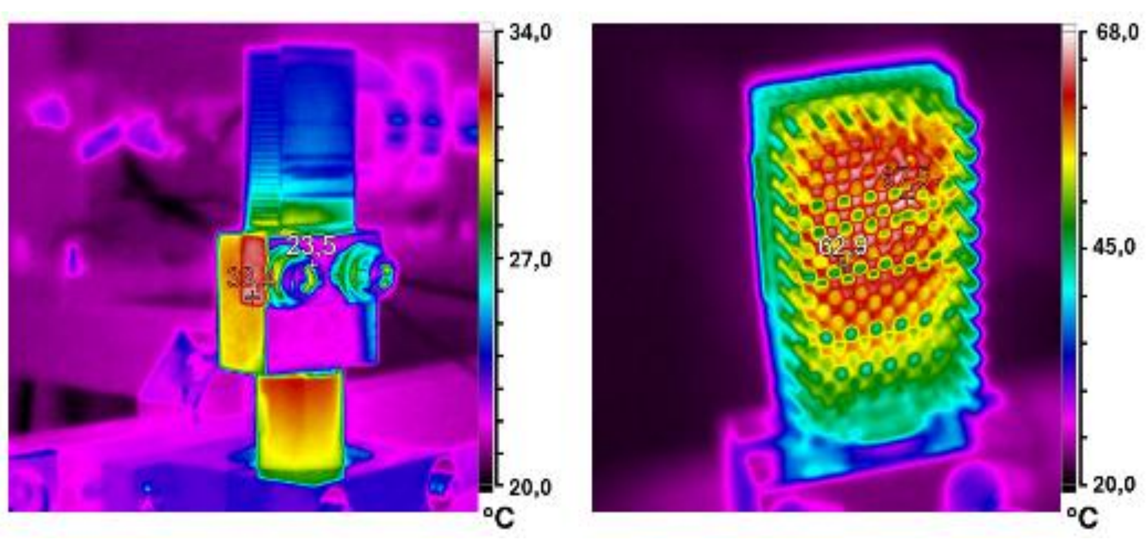


Fig. 3: Thermal recording of the energy loss with insufficient fixation (left), compared to optimized fixation (right)

Support structure design

- Support structures with an **enlarged cross-section** show better process results (with and without PBP)
- Thinner support structures are both more elastic and more resistant
- **Stress concentration** of thicker support structures highest in the transition zone
- Great influence due to **optimized mass distribution**

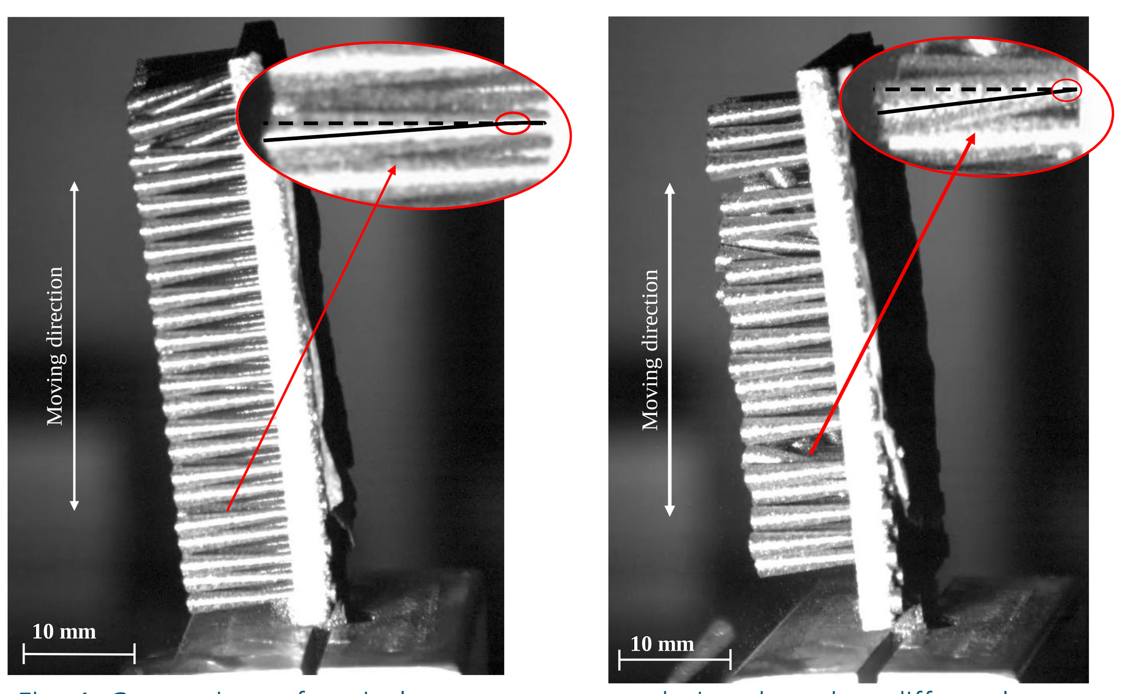


Fig. 4: Comparison of conical support structure designs based on differently dimensioned core diameters (0.5 mm left, 1.0 mm right)

Vibration behaviour

- Support structures are primarily removed in the **first few minutes** of vibration excitation
- The removal of support structures is possible by using **one restricted frequency range** (± 4 kHz)
- The **AM part also vibrates** and influences the dynamic behaviour of the support structures

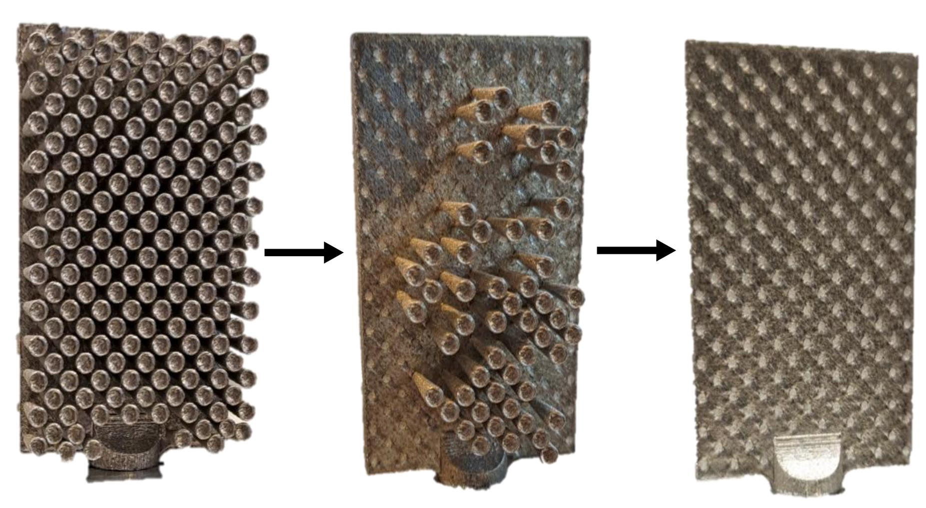


Fig. 5: States of the test sample (SM/con./1.0 mm) before, after 4 min. and after the process

Further findings of vibration-based support removal

Surface quality

- Measurements considered the fracture area (1), pure surface without support structures (2) and total surface area (3)
- In general, **vibration-based removal method resulted in significantly better surface quality** compared to manual methods (with chisel or pliers)
  - The vibration-based approach shows that the **depth of the breakouts in the fracture is significantly smaller**
  - In particular, support structures with an enlarged cross-section at the connection point exhibit **fracture behaviour close to the surface**
  - Subsequent **post-processing effort is significantly reduced**

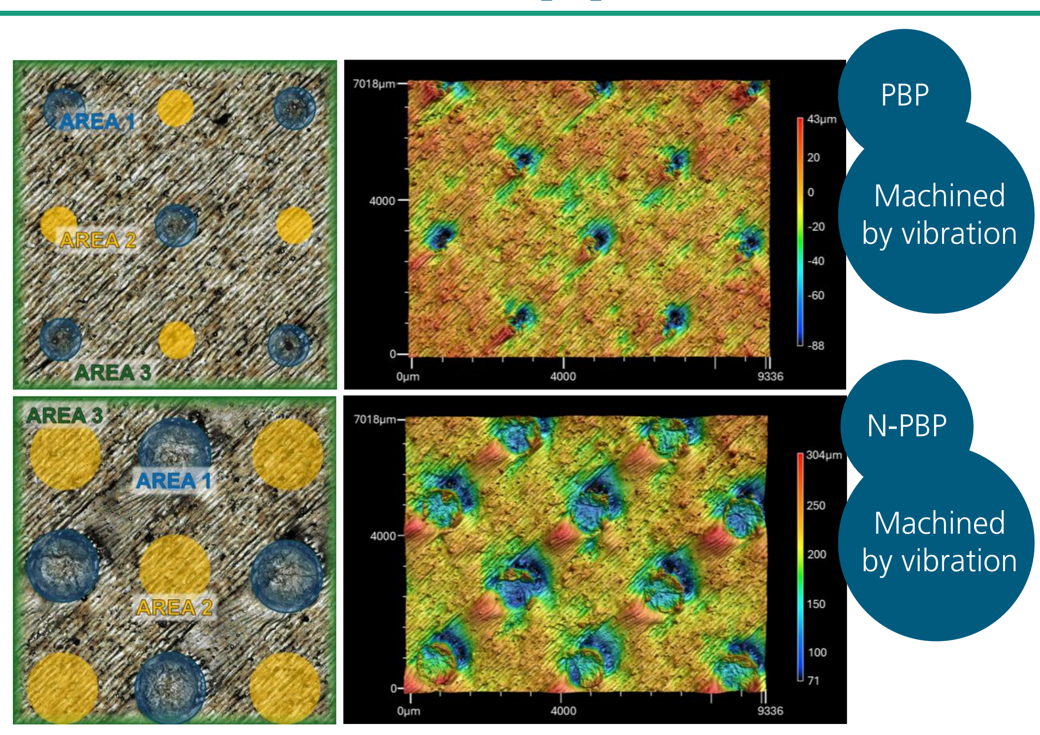


Fig. 6 + Table 1: Surface quality of vibration-processed specimen with regard to different areas evaluated by a Keyence VK-X 3000

	Area 1 [µm]		Area 2 [µm]		Area 3 [µm]	
	PBP	N-PBP	PBP	N-PBP	PBP	N-PBP
S_a	32.0	31.2	7.0	9.7	13.3	28.7
σ_{S_a}	3.6	3.7	1.8	2.5	-	-
S_z	177.8	241.0	59.4	84.5	226.8	328.1
σ_{S_z}	13.9	28.3	11.6	13.5	-	-

PBP = Predetermined breaking point; N-PBP = Non-predetermined breaking point

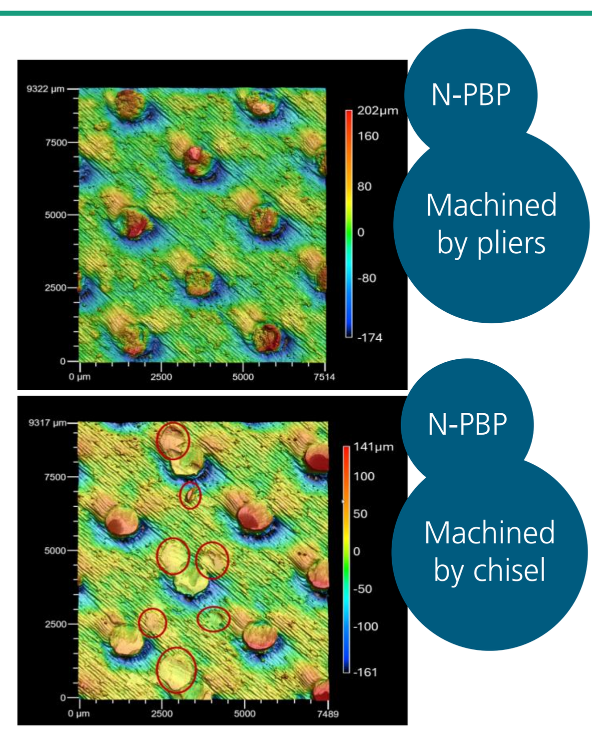


Fig. 7 + Table 2: Surface qualities of manually machined specimen evaluated by a Keyence VK-X 3000

	Area 1 [µm]		Area 2 [µm]		Area 3 [µm]	
	Chisel	Pliers	Chisel	Pliers	Chisel	Pliers
S_a	56.8	56.9	8.8	9.8	36.1	31.3
σ_{S_a}	8.7	10.5	1.6	1.2	-	-
S_z	340.4	338.3	84.8	88.1	413.7	416.9
σ_{S_z}	24.6	28.7	9.5	7.3	-	-