Comparative investigation of AlSi12 from classic and 3D-printing production route

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Introduction

3D Printing is a branch of additive manufacturing technologies which is being continuously developed and is becoming more and more important for industrial applications. It is not only a valuable method for rapid prototyping, but it finds its special applications in the manufacturing of complicated components e.g. in the medical and in the aerospace industry. The goal of this study is a comparison of two production routes for an aluminium braze. One sample has been produced with the conventional production route. The other samples has been 3D-printed with the selective sintering laser method (Figure 1). The chosen alloy AlSi12 is one of the most common types used in aluminum brazing and is usually found as a coiled wire material. Several tests were conducted to compare the mechanical and brazing properties of a standard AlSi12 wire and a 3D printed one. The results can be used as base for further exploring the applicability of 3D printed components as braze.

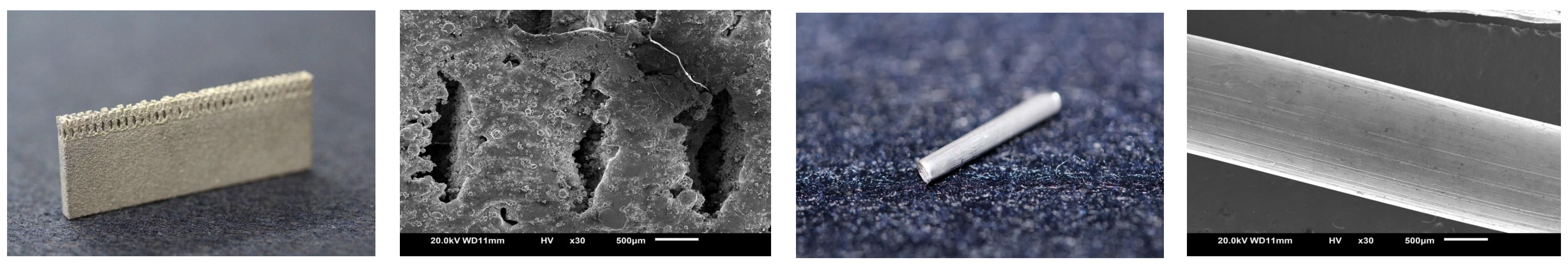


Figure 1: Digital camera and SEM documentation of the 3D-sample (left) and the wire (right)

Effect of cold rolling on hardness

A classical test is the comparison of the hardness development of a metal as a function of the degree of deformation. A laboratory rolling mill was used to create samples with different degrees of deformation. The change in hardness of the samples was measured and recorded using micro hardness according to Vickers HV 1 (Figure 2). The hardness of the classic production route wire sample is recorded parallel to the rolling direction. Due to the very brittle behavior of the 3D printed sample, and the rough surface, the hardness of this sample could be only recorded after the samples were cold mounted in epoxy resign and metallographically prepared. The hardness for those samples was respectively measured lateral to the rolling direction. The wire proved to be very ductile and retained a comparatively low hardness even at high degree of deformation. The 3D printed sample had a significantly higher hardness and showed highly brittle behavior after approximately 30% deformation of the initial dimensions the sample cracked into multiple separate pieces (Figure 3).

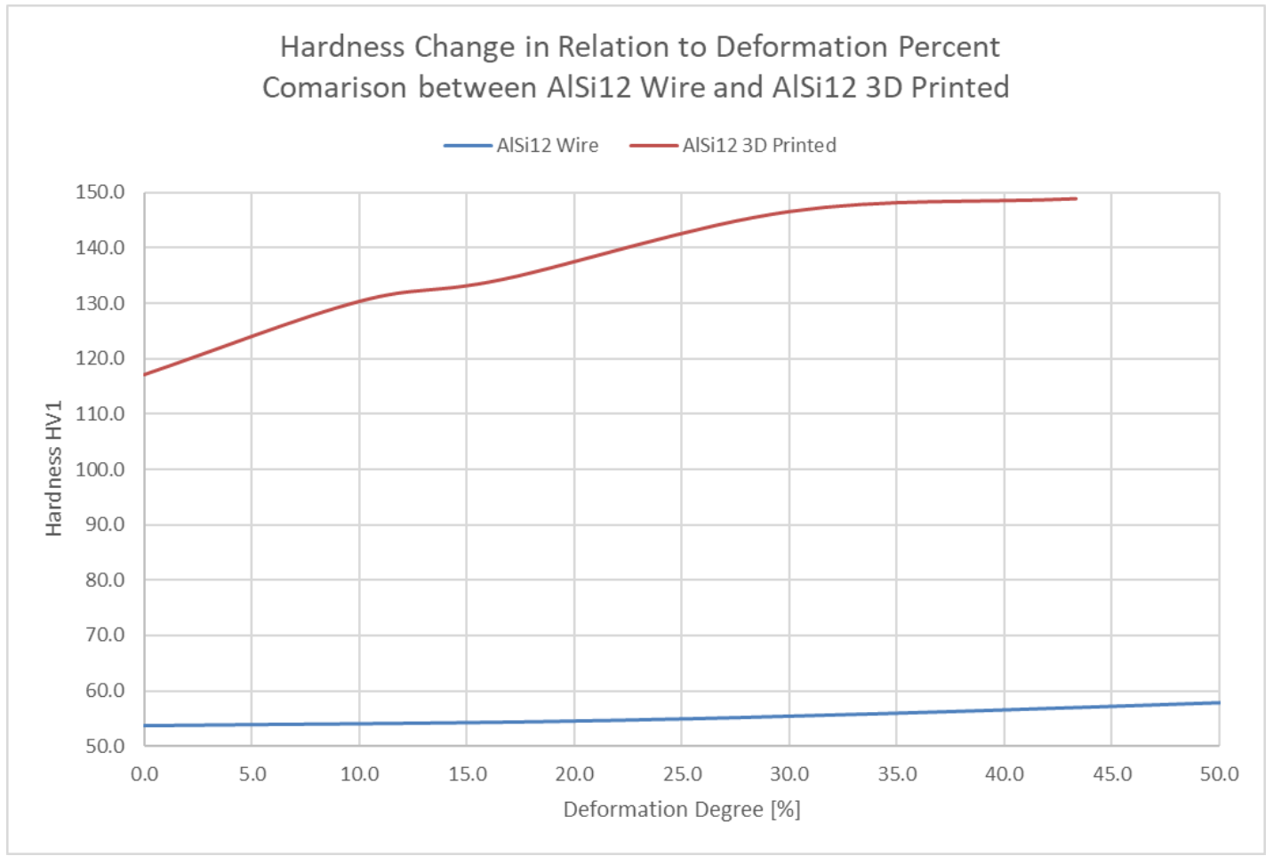


Figure 2: Hardness vs. Deformation Degree plot

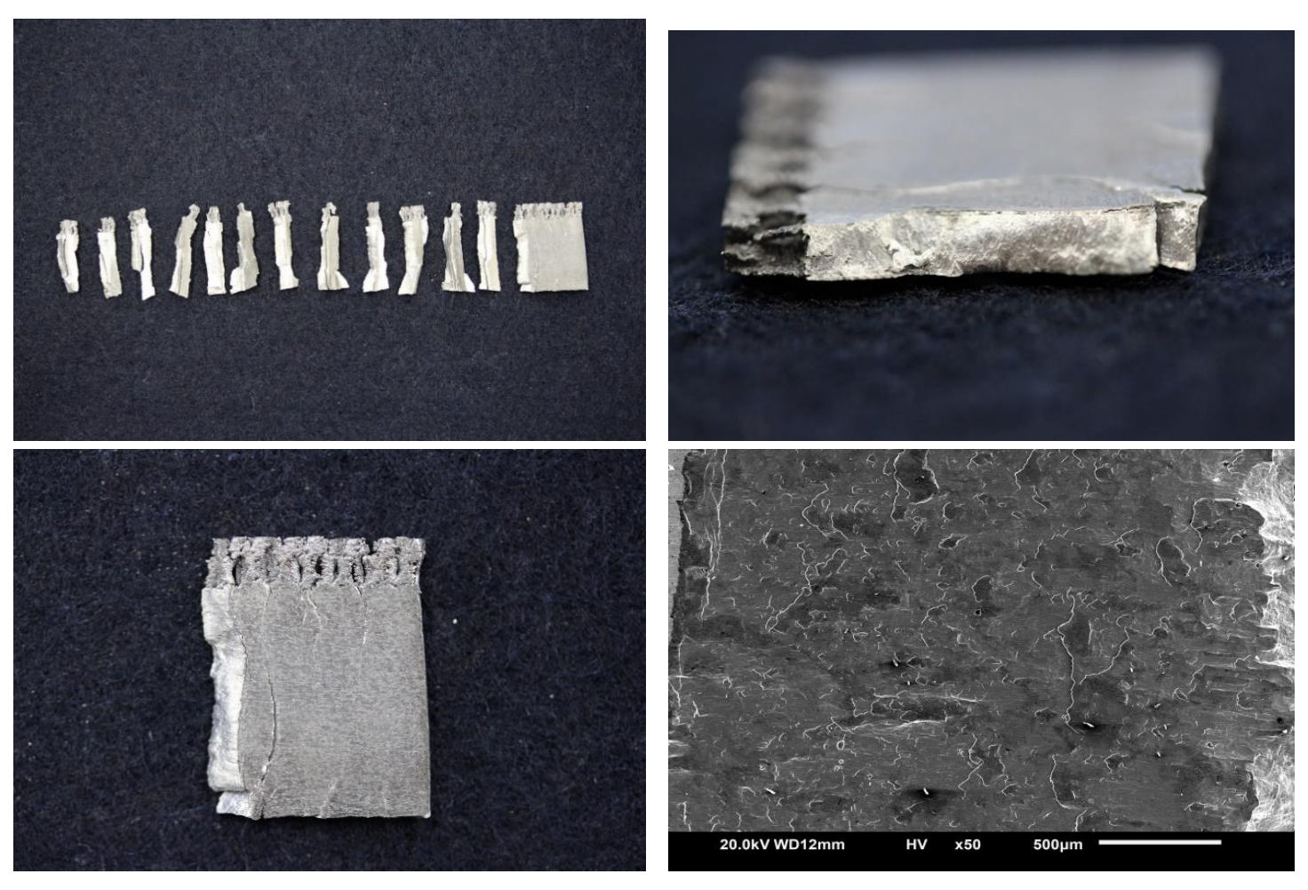


Figure 3: 3D-Sample after 30% deformation, SEM pictogram shows brittle fracture surface

SEM and 3D Light Microscope Documentation

To be able to visualize and compare the surfaces the samples were documented with the aid of a three-dimensional light microscope (VHX 2000, Keyence) and a scanning electron microscope (JSM IT-100, Jeol). The resulting profiles can be seen in Figure 4 below. Apart from the cylindrical profile of the wire sample and several longitudinal scratches, the 3D printed sample has a much rougher surface. From the SEM pictures it can be observed that there are also some droplets which have not been completely molten and which are statically attached on the surface which also leads to a high surface roughness profile.

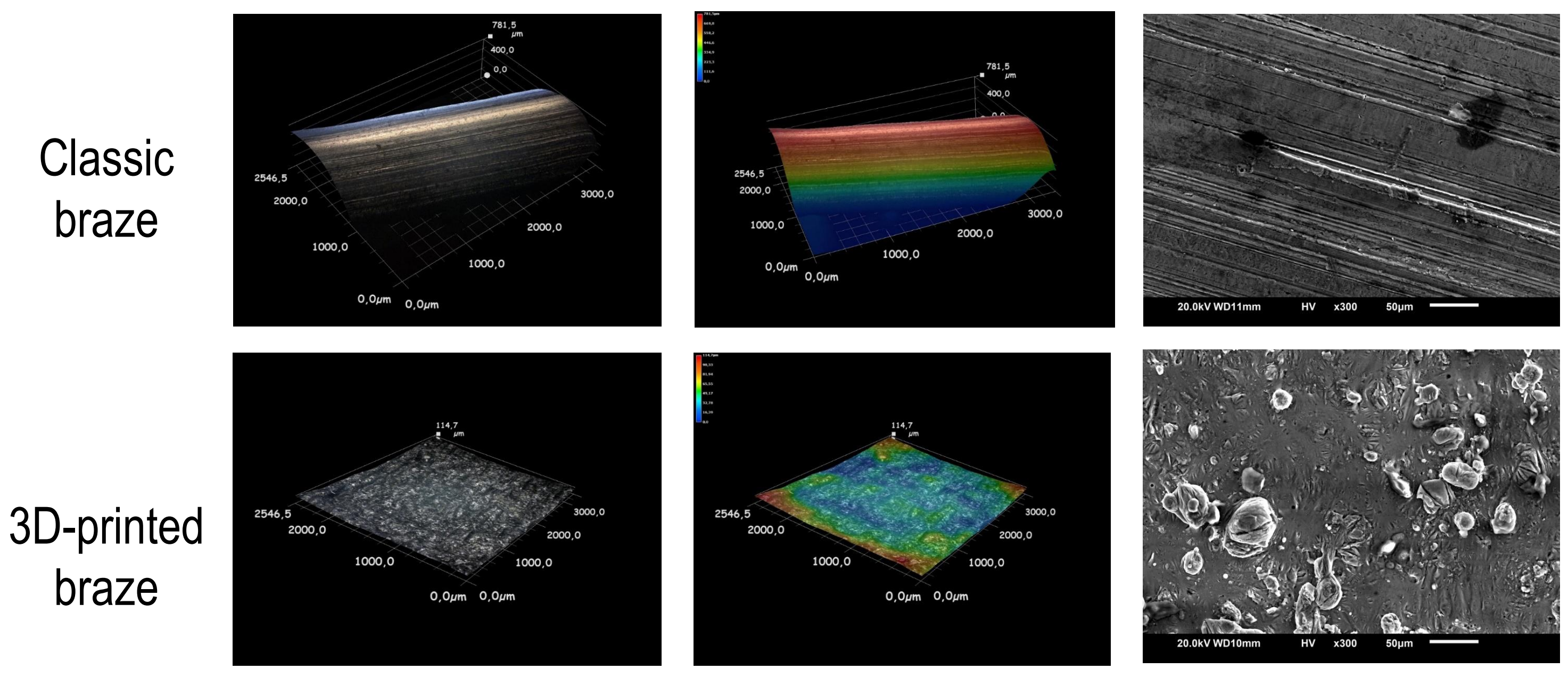
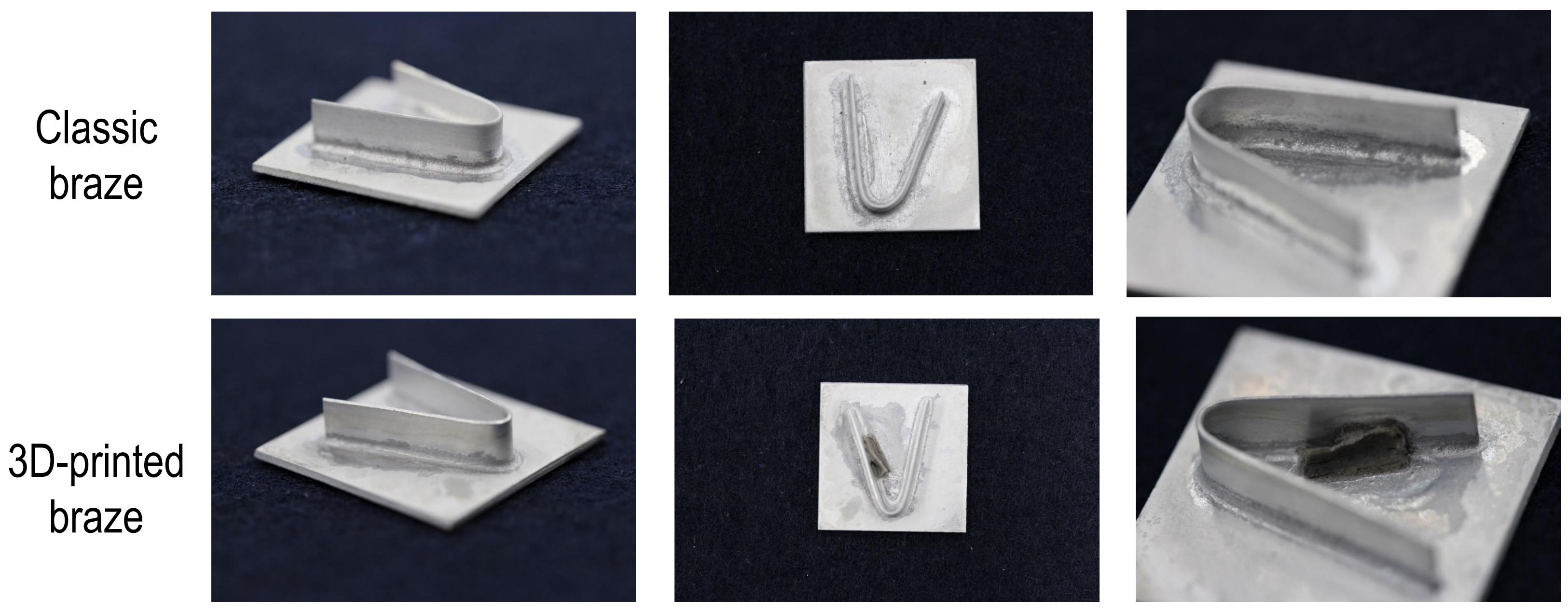


Figure 4: 3D Light Microscope and SEM documentation of the surface

Brazing Simulation

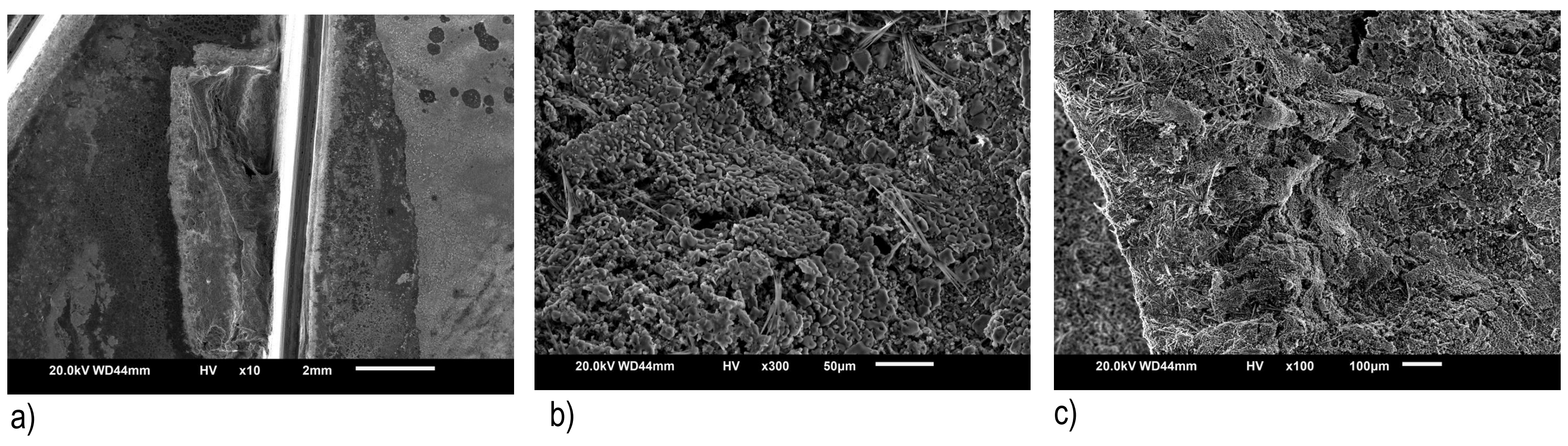
To explore the brazing behavior a brazing simulation angle and coupon test was conducted in a nitrogen gas shielded glass furnace. A typical brazing cycle, consisting of heating the sample up to 600 °C with a heating rate of 20 °C/min and holding it on that temperature for 3 minutes was used. The nitrogen shielding gas flow was set at 8 l/min. The typical amount of Nocolok© flux was applied in both cases with the help of acetone to achieve an approximate 20 g/m² coverage. The brazing results in both cases are satisfactory, a good and regular fillet was formed with both types of brazes (Figure 5). An important phenomenon which occurred when using a piece of the 3D printed material was the unusual scale formation which had retained the approximate shape of the piece of material used as braze.



Fgure 5: Results of angel-on-coupon tests

EDX and DSC Analysis

To determine the chemical composition of both samples an EDX analysis was performed. The approximate chemical composition is shown in Table 1. Furthermore, the chemical composition of the scale that remained was also examined using EDX analysis. As it can be seen the oxide scale had two diverse types of structure which could be observed under the scanning electron microscope (Figure 6). Using spot analysis, the respective chemical compositions of both were recorded. They consist of flux residues containing fluor and potassium from the flux as well as magnesium from the 3D-printed braze.



a) b) c)

Figure 6: SEM Documentation of: a) overview of the scale formation after brazing with the 3D-Printed braze, b) Enlarged view of the sponge oxide structure on the scale, c) Enlarged view of the spike oxide structure on the scale

Table 1: Chemical Compositions according to EDX-analysis

Sample	**O** *[w%]*	**F** *[w%]*	**Mg** *[w%]*	**Al** *[w%]*	**Si** *[w%]*	**K** *[w%]*
3D Print Initial State	3.86	--	0.96	83.62	11.56	--
3D Print after DSC	2.18	--	1.3	68.03	28.49	--
Wire Initial State	1.85	--	--	84.59	13.56	--
Wire after DSC	5.09	--	--	67.89	27.01	--
Sponge Oxide Structure	11.95	22.15	0.2	13.78	0.35	51.57
Spike Oxide Structure	11.06	42.96	7.03	17.73	0.34	20.88

To determine the exact behavior of both materials during brazing, differential scanning calorimetry analysis were conducted (Figure 7). The results of the analysis show that the conventionally manufactured AlSi12 wire has single peaks on the heating and cooling curves. The melting and solidification temperatures for this material were 593°C and 573°C respectively . Whereas for the 3D printed sample two peaks can be seen on both the heating and cooling curves. The first large peak on the heating curve is at a temperature of 593°C and it is followed by a smaller peak at 600°C. On the cooling curve two separate peaks are clearly visible. The first peak on the cooling curve which corresponds to the smaller peak on the heating line is at 590°C and the second peak on the cooling curve is at 573°C. The two different peaks are a clear proof for a second phase in the alloy which must be related to the Mg which was found in the 3D printed sample during the EDX analysis.

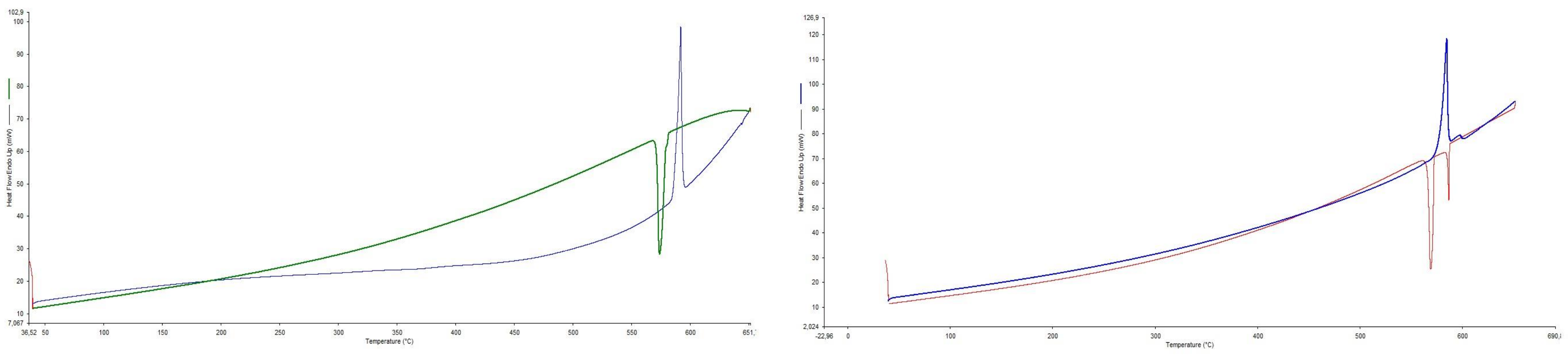


Figure 7: DSC analysis curves, AlSi12 wire on the left and 3D-Printed AlSi12 on the right

Interesting phenomenon found during the DSC analysis was that the test piece had retained its original shape. This effect strongly resembled the scale formation during the brazing simulation. Since the scale, formed during brazing, showed an oxide composed of magnesium, potassium and fluorine it could be concluded that the reason for this oxide formation was the reaction between the flux and the Mg. This reaction than formed the scale on top whereas the molten braze flew to fill the gap and create the joint between the angle and coupon. But in the case of the DSC test there was no flux present during the heating. The fact that the sample had retained its initial shape even though the test results showed both a melting (endothermal) and solidification (exothermal) peak, requests further investigation. Analyzing the samples again using EDX showed that there is an increase of the Mg and Si content but a lower oxygen content. One probable reason for this phenomenon can be the initial higher oxides content due to the rapid melting and solidifying during laser sintering. The retainment of the initial shape of the piece can be attributed to the higher surface energy of the oxide layer that is formed on the sample. Without the presence of flux to break the oxide layer and allow the liquified metal to flow the sample retained its original shape and was later solidified again.

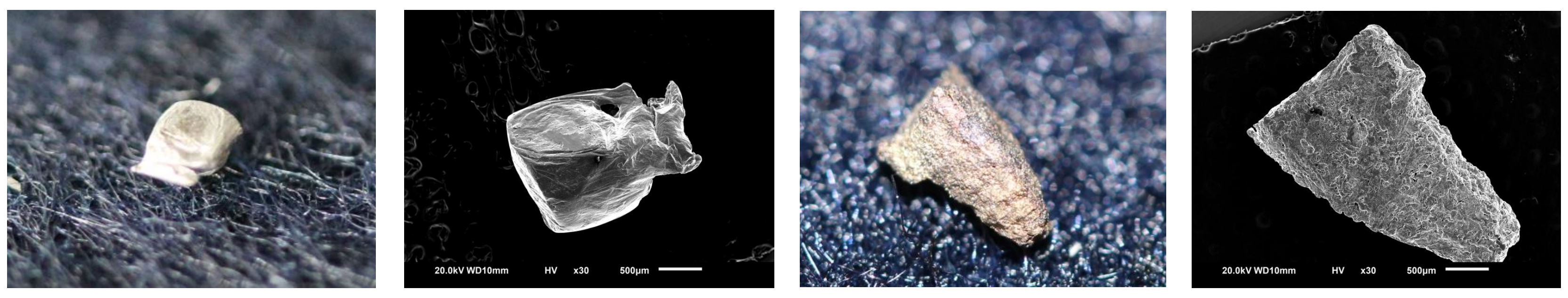


Figure 8: Samples after DSC analysis digital picture and SEM pictogram, AlSi12 wire on the left and 3D-Printed AlSi12 on the right

Conclusion / Discussion

Significant differences between the hardness of the 3D printed sample and a conventionally produced AlSi12-wire sample could be observed. Since the output state from manufacturing is not exactly know it is difficult to asses the reason for the large difference in the initial hardness of both samples. The behavior of both samples when deformed is respectively very different. The wire is very ductile and even after large deformation retains comparatively low hardness, whereas the 3D printed material increases its original hardness significantly. Reasons for the substantial increase in the initial hardness of the 3D printed material are not only the increasing dislocation density but also the compaction of the material and decrease of the residual porosity. The brazing simulation results showed similar joining capabilities for both the conventional wire and the 3D printed sample, with the main difference of an oxide scale formation in the case of the 3D printed material. The chemical composition of the scale showed an oxide composed of the Mg originally found in the material and the KF salt from the flux. The thermal analysis showed slightly higher melting temperature for the 3D printed material which can be contributed to the higher oxide content due to the laser sintering. The two peaks in the results of the 3D printed material clearly indicate a second phase which is probably linked to the Mg originally contained in it. An interesting phenomenon observed was the retainment of the original shape after the DSC analysis. With the data gathered this occurrence may be contributed to the higher oxide level in combination with the Mg content. Further research is required to explore the possible application of this phenomena for instance in the use of braze preform.