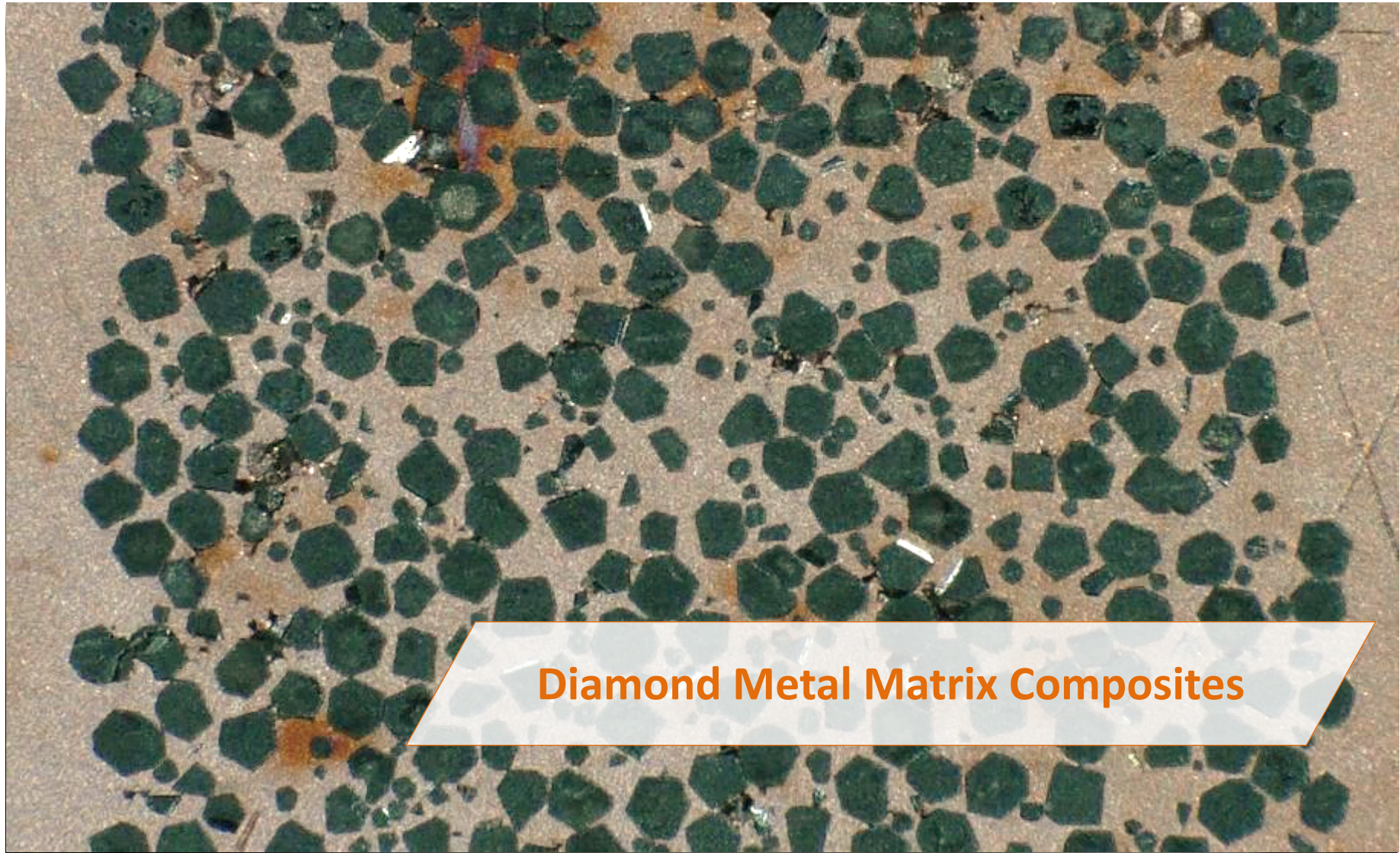


PoC project: Investigation of new methods for the manufacturing of Copper-Diamond composites with tailored thermo-physical properties






D.Grech, E.Neubauer

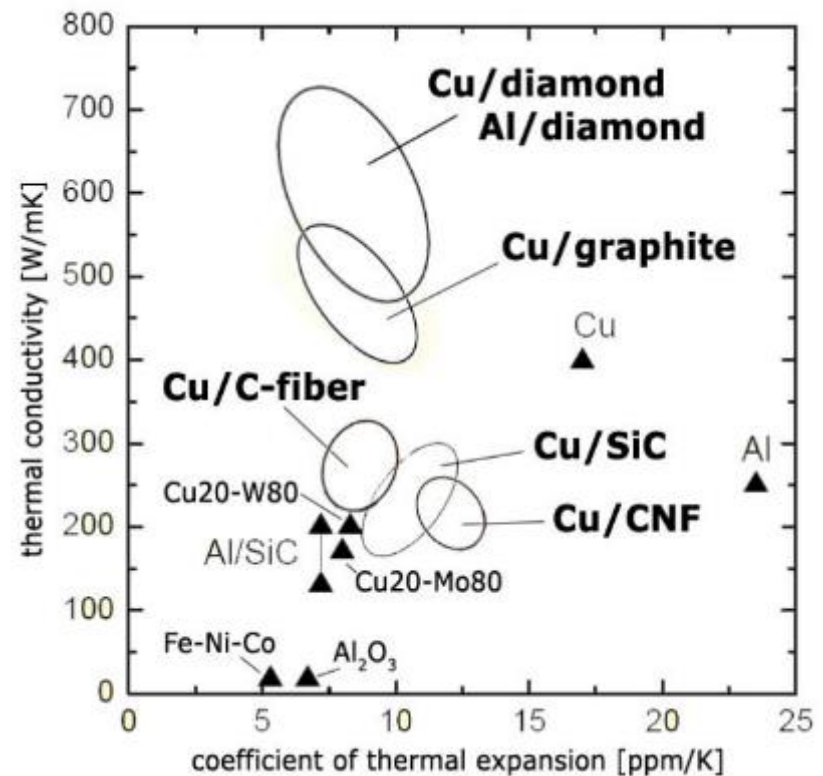
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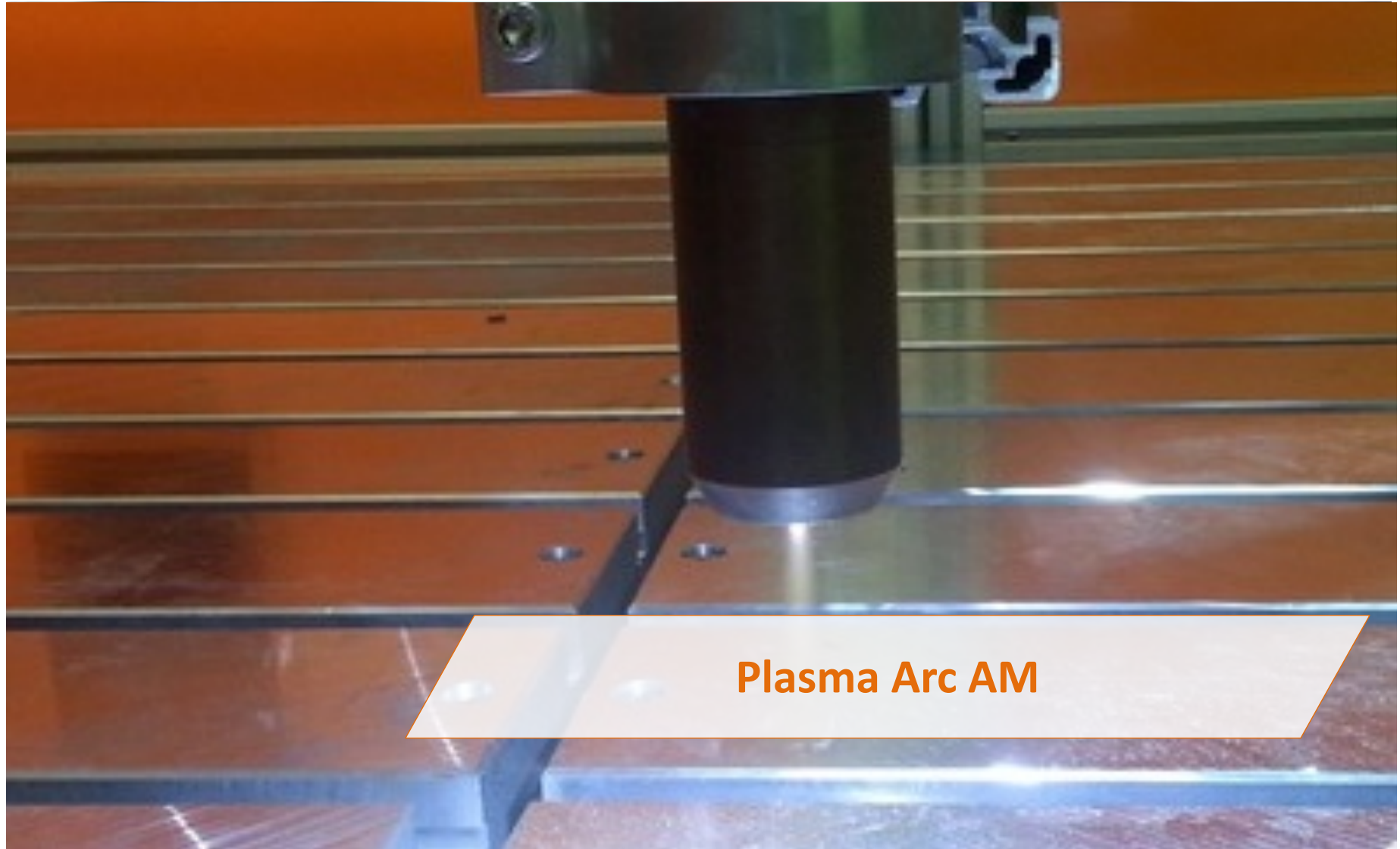
Diamond Metal Matrix Composites

-  Combining the properties of diamond and metals
-  Address gap for high thermal conductivity (TC) and low Coefficient of Thermal Expansion (CTE)
-  Isotropic properties
-  Applications for cooling of electronics or laser components
-  Potential application for collimators in LHC



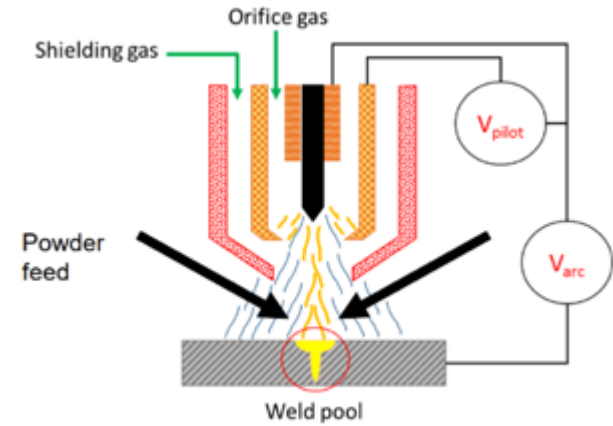
Source: adapted from Th. Schubert, Euromat 2009, Glasgow

-  Explore the use of Plasma-Arc Additive manufacturing techniques for Diamond based metal matrix composites for building up layer by layer
-  Assessment of several manufacturing concepts to achieve samples of Diamond Metal Matrix Composites using a plasma arc process
-  Composites with >30vol% Diamond content are targeted
-  Enhanced thermal conductivity and lowered CTE due to diamond content
-  Preparation of test parts and analysis of thermal properties

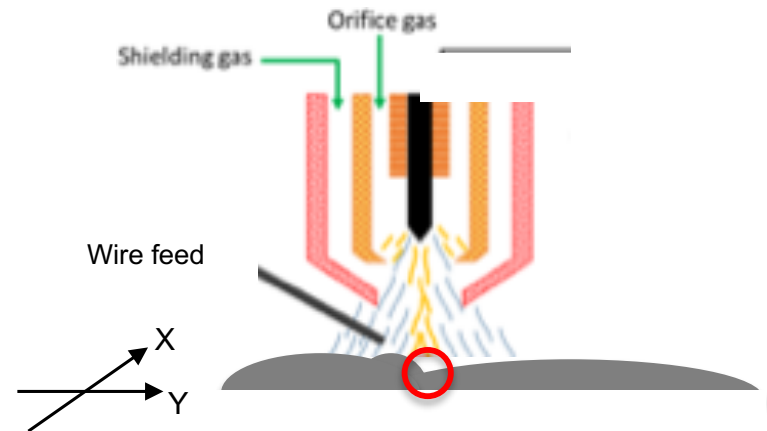


Plasma Arc AM

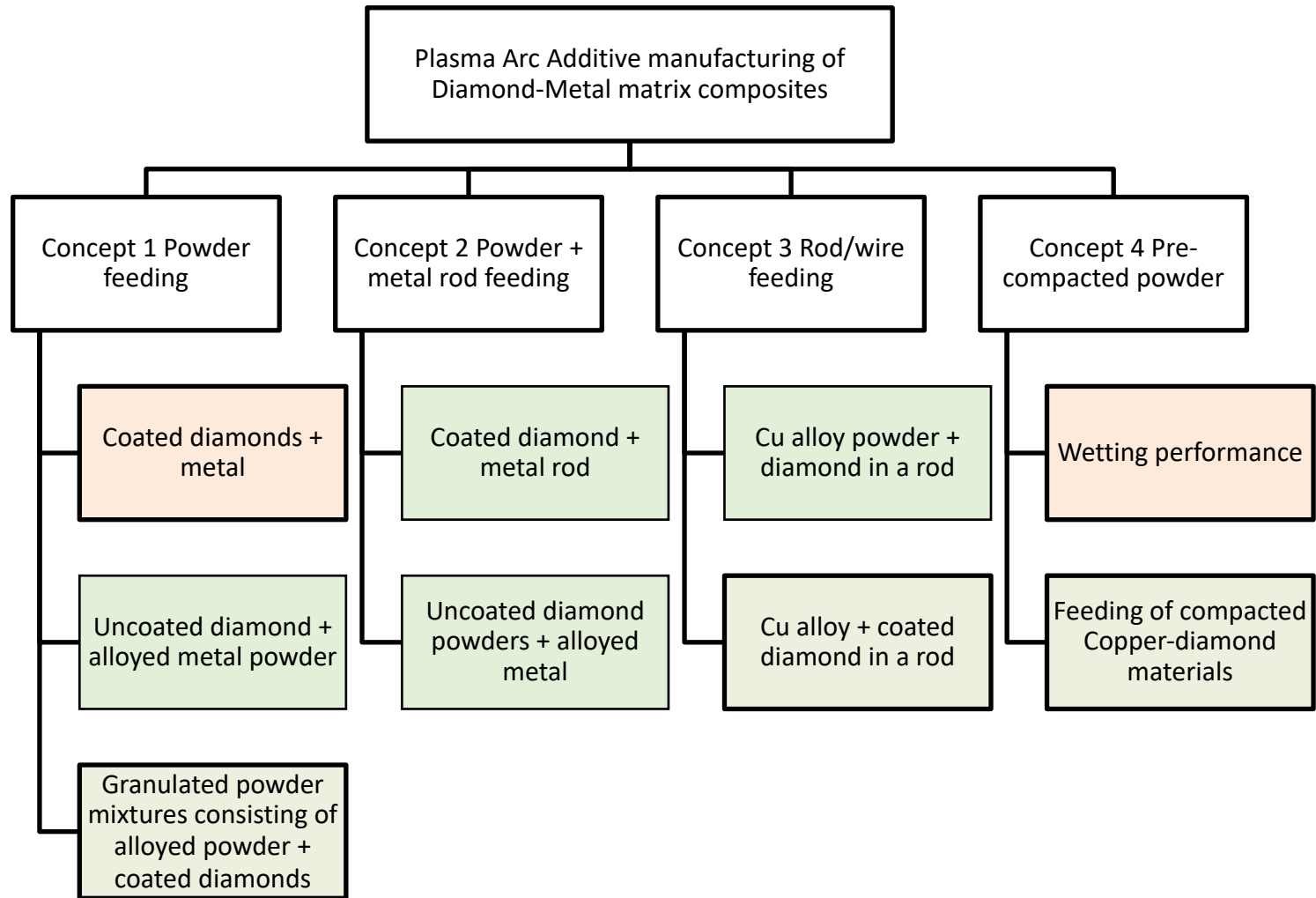
Blown Powder












Wire Feed




Main idea: use of the Plasma Arc method for the manufacturing of metal diamond composites using blown powder/wire feed method








 After the first assessment of various concepts several challenges observed:






-  Issues with substrate interaction
-  Diamond graphitization
-  De-Wetting with the liquid melt
-  Separation of the diamond
-  Overspray
-  Inhomogeneity
-  Oxidation
-  Difficult to feed using the standard powder feeder
-  ..and many more

 Need for detailed analysis and separation of “challenges” into the development of smaller building blocks

Pre-cursor materials

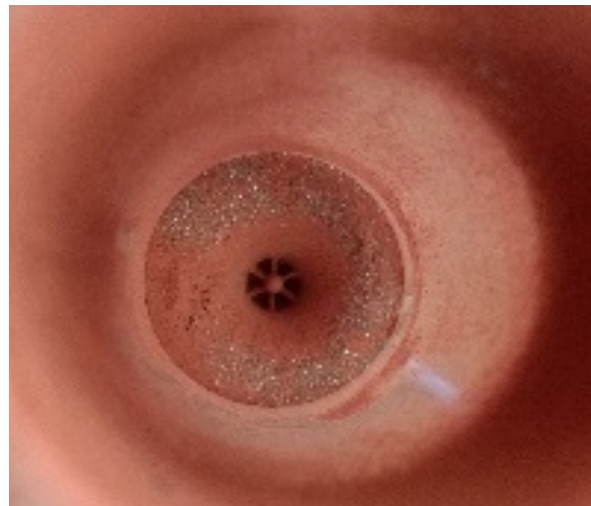
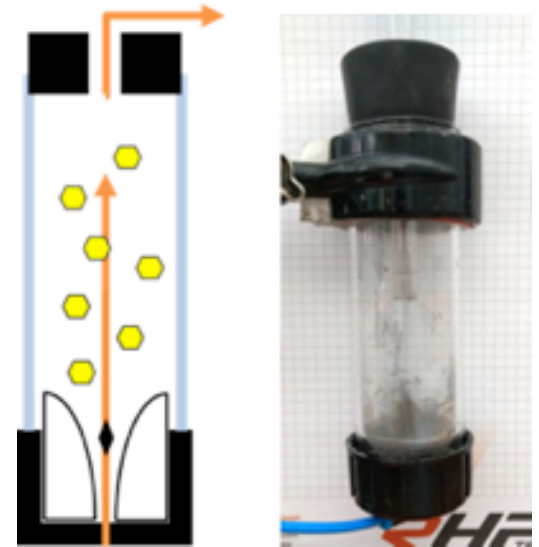
-  Challenge 1: standard powder feeding system is not suitable for processing powder mixtures containing diamonds
-  Challenge 2: there are no suitable “feedstocks” (wires) available
-  Challenge 3: protection the diamond/enable wetting in the matrix
-  Challenge 4: Controlling/avoiding of de-wetting between diamonds and the liquid matrix
-  Challenge 5: Oxygen sensitivity of the matrix

Processing of composite materials using plasma arc

-  Challenge 6: Avoid graphitization of diamond
-  Challenge 7: Homogeneous distribution of diamond particles
-  Challenge 8: High diamond loading (>30 vol%)
-  Challenge 9: Manage homogeneity in multilayers
-  Challenge 10: Achieve required thermal properties

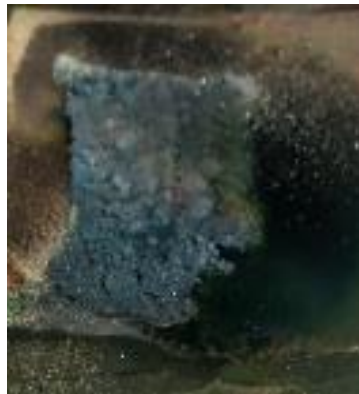
Challenge 1: Feedstock preparation/transport for further processing

- Approach #1: Design of a powder feeding concept
- Powder feeding of dissimilar materials is difficult with standard feeding systems
 - Large diamond grains (regular)
 - Irregular metallic matrix
 - Risk of separation/segregation during feeding/clogging
 - Wear and abrasion of the moving components in classical feeding mechanisms








Blown diamond powders

- Using the feeding system a combination of Cu wire + titanium coated diamond powders was tested
- Use of Mo substrate to minimize uptake of Fe and Ni into melt pool → known graphitization catalysts
- Temperature dependent wetting of Cu on Mo unless under H_2
- H_2 dissolves in Cu at high temperatures, which then escapes during cooldown, leading to severe porosity/foaming
- Mo substrate was heating up to rapidly, leading to severe spreading of Cu
- Using of high gas flow results in severe overspray and turbulences in the powder; too less flow rate results in an oxidation of matrix.



Challenge 1: Feedstock preparation for further processing

 Approach #2: Assessment of granulation processes to enable:

-  better distribution of diamonds inside the matrix
-  Less wear and clogging issues in powder feeding system
-  Less overspray => higher gas flow possible
-  Granulates are pre-sintered



Cu alloy+ dia
A19-240



Cu+diamond
A19-241








Cu alloy + diamond
A19-242

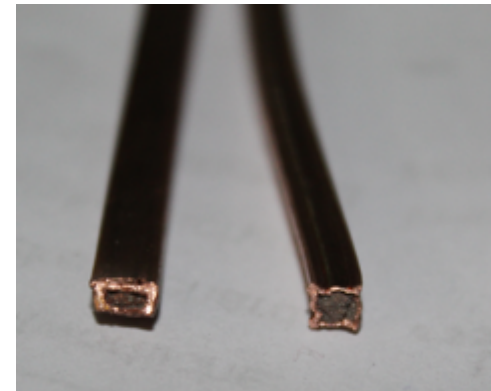
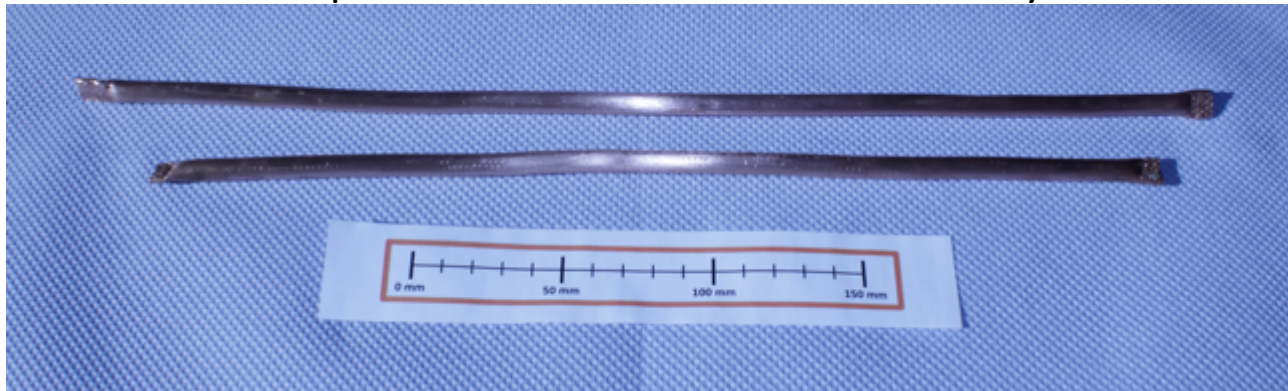
Challenge 1: Feedstock preparation for further processing

- Approach #3: Assessment of pre-compaction of plates and ingots for further processing
- Assessment of compaction/densification behavior of different alloys (Cu alloy + diamond particles) for preparation of weldable ingots
- Compaction for material preparation of up to 50 vol% of diamonds was confirmed



Challenge 2: No commercial filled wires available

-  Approach: Demonstration of a fabrication for a metal-diamond "wire" which can be fed into the plasma torch avoiding the severe overspray
-  A process for the preparation of a filled wire was established using a Cu envelope which is filled with the metal diamond powder
-  Filling of the Cu envelope can be done with a mixture of 50-60 vol% of diamond
-  Including of Cu envelope a final concentration of 30-40 vol% can be achieved
-  First tests were done with copper and coated diamonds; next steps are to be done with selected alloys from #4.





Challenge 3: protection the diamond/enable wetting in the matrix



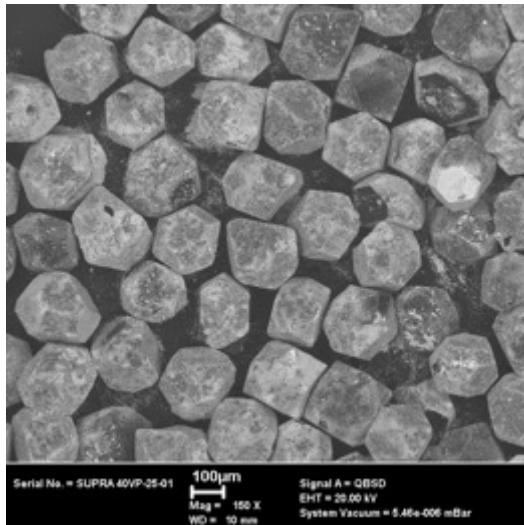
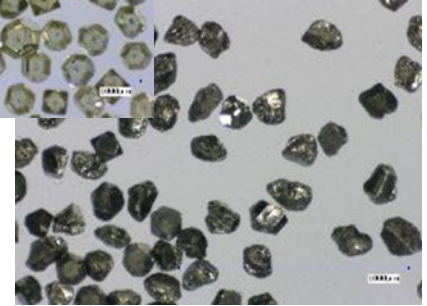
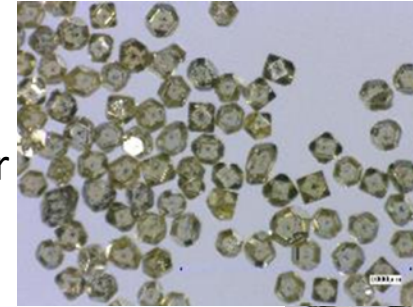
Approach: Coating of diamonds with functional layers for different diamond grain size suitable for the powder feeding



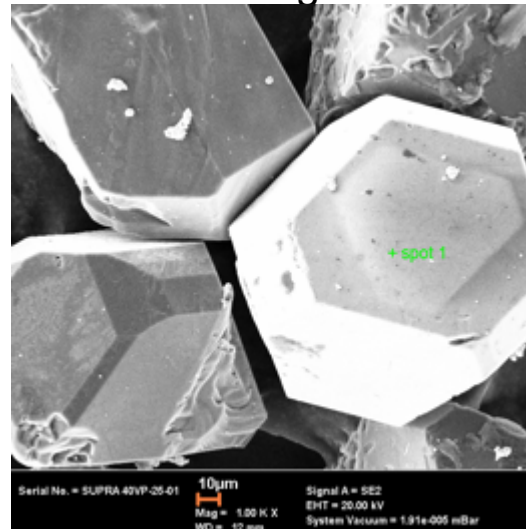
Coating was done by using thermo-diffusion processes.



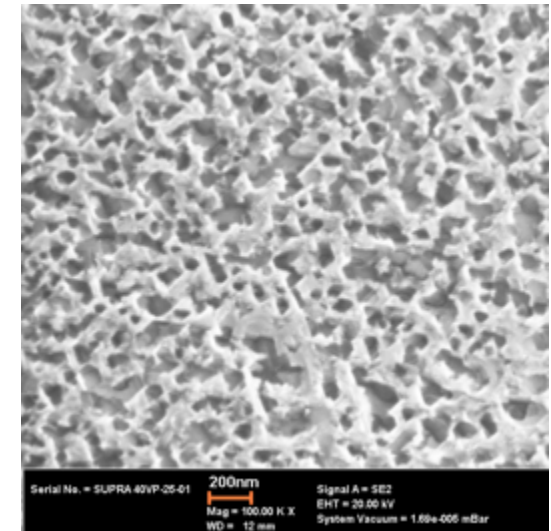
Various metals can be applied, e.g. Cr, Mo, W with different thicknesses to protect the diamond and additionally to promote the wetting



W- coating



Mo- coating



Magnification



Challenge 4: Assessment of various copper alloys to minimize the de-wetting



Combined approach: using of coated diamonds and appropriate copper alloys



Lessons learned: only coating is not sufficient, we need both due to the short contact time



More than 20 combinations of Cu alloys with different coated diamonds have been assessed



Dewetting can be observed and result for some alloys in a partial or complete separation of the melt



Four promising candidate combinations have been identified where no dewetting was observed when bringing the material above the melting point



Dewetting of the material

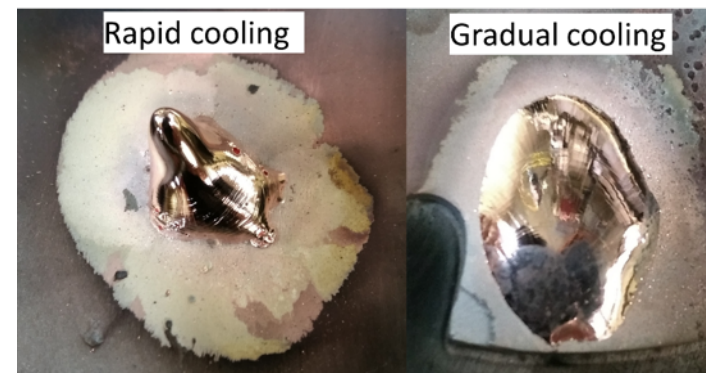
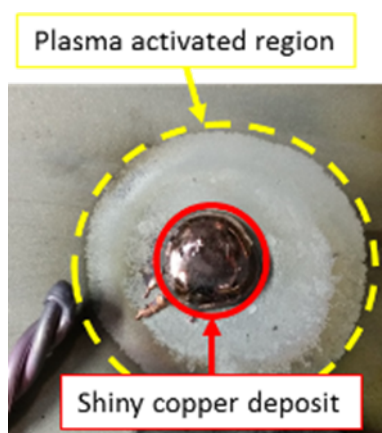


Sample without dewetting



Challenge 5: Minimize the oxidation of the matrix by using in protective/reducing environment

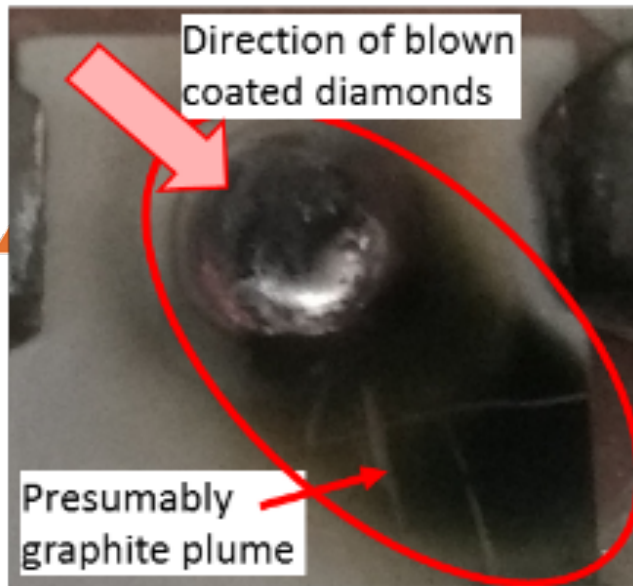
- Approach Minimize the oxidation of the matrix by using in protective/reducing environment
- Severe oxidation of the matrix was observed using of argon as shielding gas
- High flow of argon gas solves this issue but causes a loss of the diamonds
- Forming gas gives very good results but more difficult to handle and hydrogen can result in a pore formation in copper





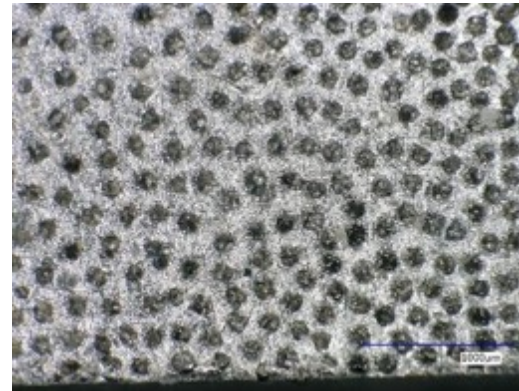
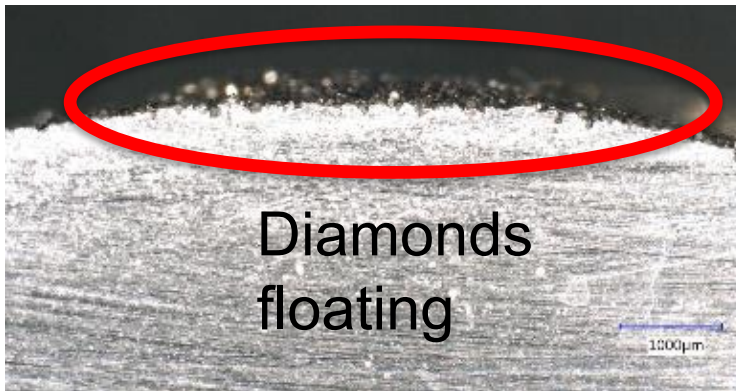
Challenge 6 :reduction of the thermal impact/apply sufficient high shielding gas to protect the diamonds

- Approach: reduction of the thermal impact is required on the diamonds
- Feeded diamonds are graphitized => coating can help to protect them
- Reduction of temperature required or using higher gas flow
- High shielding gas to protect the diamonds=> in this case severe overspray is observed.
- Additionally turbulences by the gas flow create irregularities in the distribution
- Dedicated argon box would be required to solve this issue



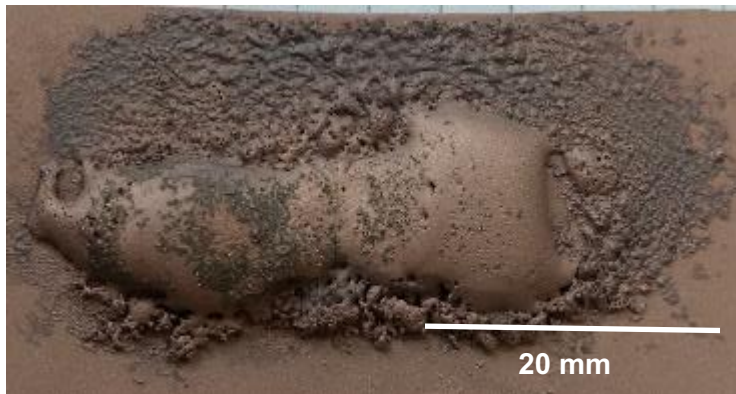
Challenge 7: Homogeneous distribution of diamond particles

- Approach: A good wetting is important to obtain a continuous arrangement of the diamond particles in the metal
- Diamond floating is a problem if a good wetting cannot be ensured
- Trials were made to minimize the difference between the density of the matrix and the diamond when using Aluminium and diamond with similar density;
- Floating of diamonds to the top was observed.



Challenge 7: Homogeneous distribution of diamond particles

- /// In copper diamond a similar behavior is observed
- /// Since the same effect was observed in Al-diamond it cannot be linked to the specific density or ratio of densities between the metal and the diamond
- /// Wetting is here also one of the main issues => results from # 4 have been applied using the combined approach of coating + copper alloy to have a sufficient wetting





Challenge 8: High diamond loading (>30 vol%)



Approach: The control of the loading and finally the homogeneity is a difficult issue. The diamonds are floating to the top layer where a high concentration is observed.



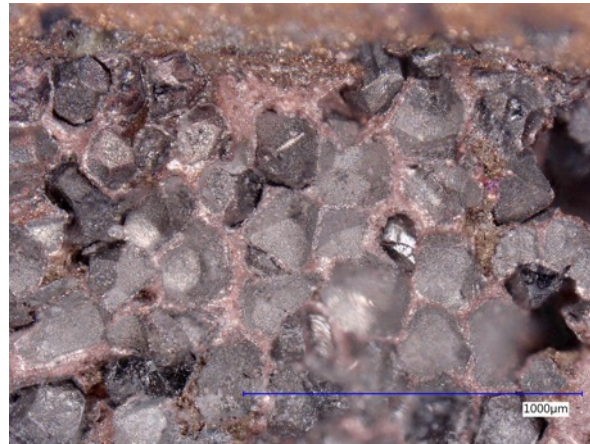
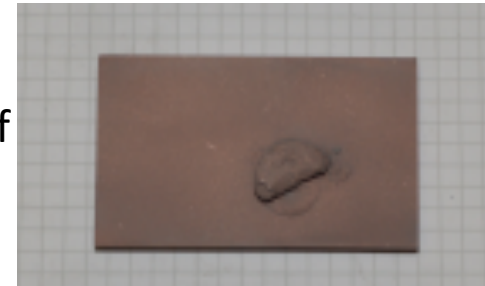
Wetting is important and be improved by changing the alloys.



Using high content of diamond volume concentration (>50 vol%) results in a dilution down to 30 vol% if additional matrix material is used



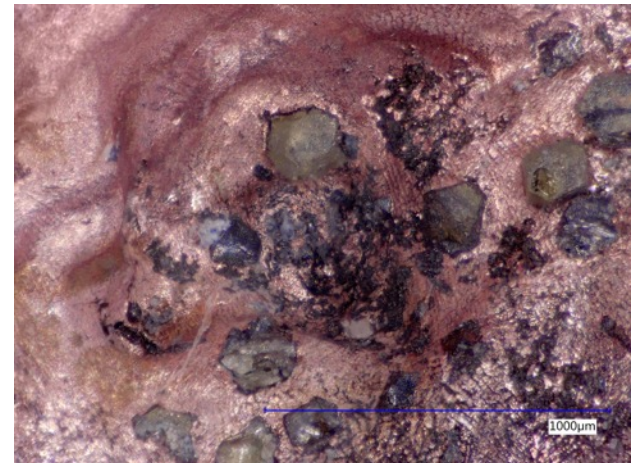
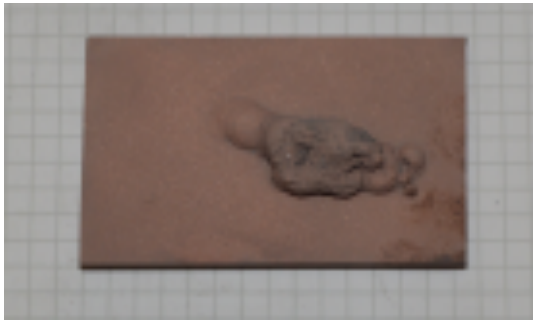
Bonding to the substrate is an issue; needs a good control of processing parameters to avoid a deformation of the substrate





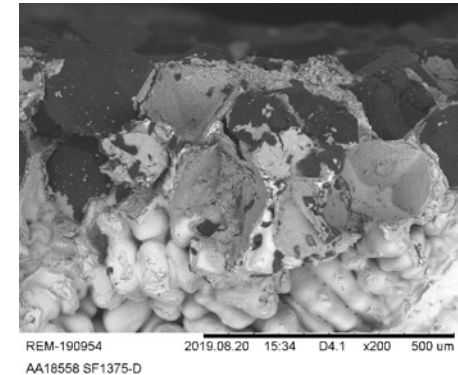
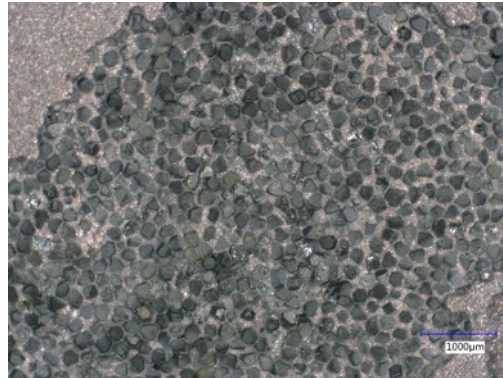


Challenge 9: Manage homogeneity in multilayers and shape





- Control of the geometry and shape of the structure is very challenging
- High temperature/power is required to enable good wetting of the diamonds but this results in a loss of the shape
- Eventually controlled cooling/heating of the substrate is required to have more stable temperature conditions.

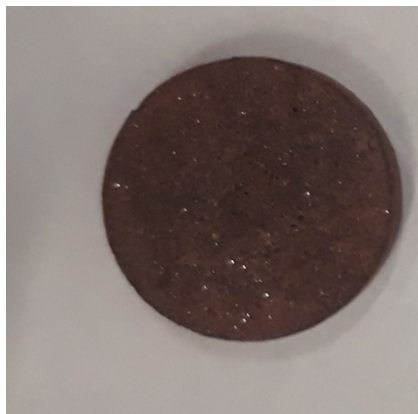


-  Based from experiments from wetting tests using a shape/mould it is possible to keep the shape
-  Surface finish is still an issue and needs to be controlled in a better way

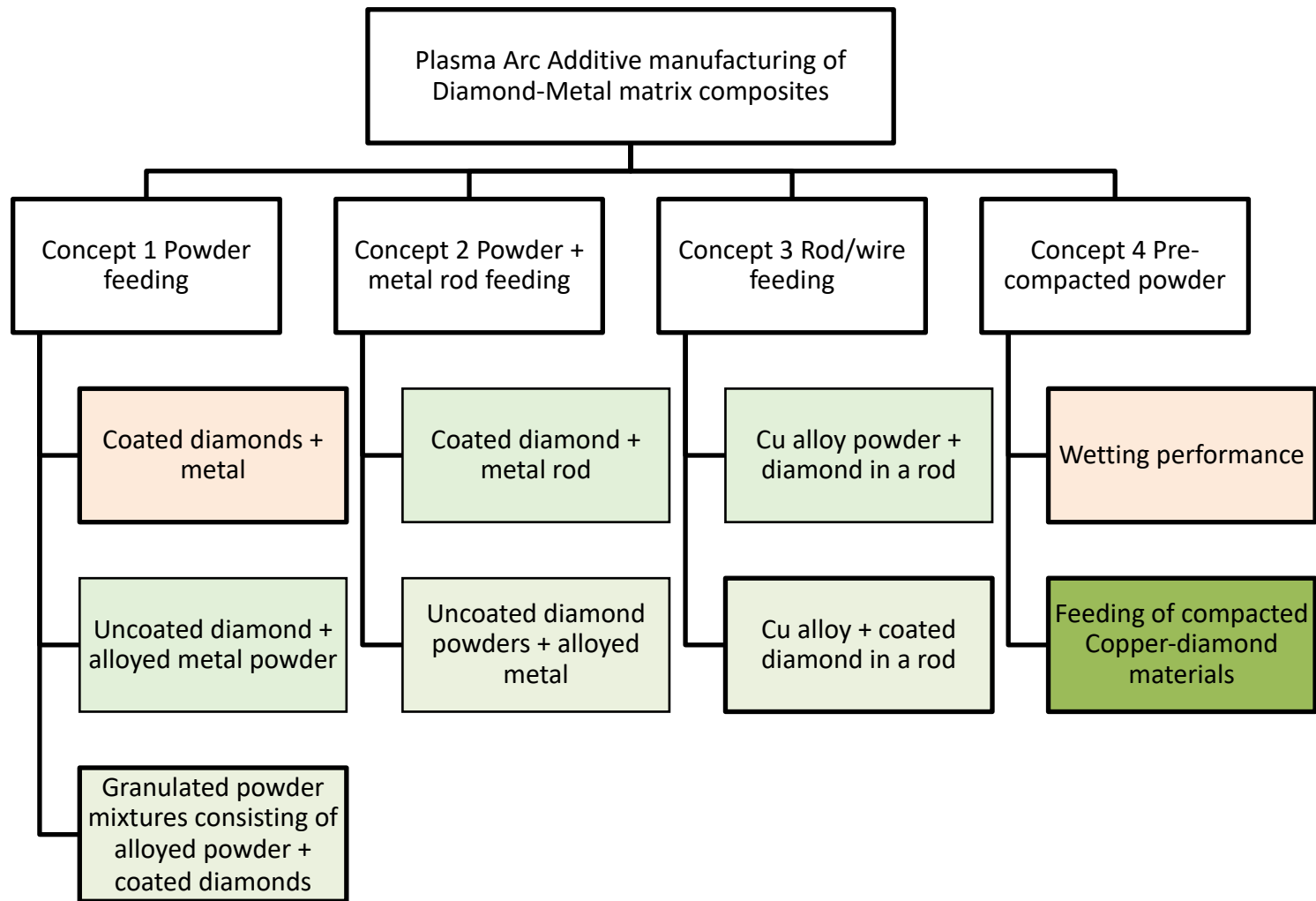











Preparation of samples using moulds to control the shape

-  Using combined materials (coated diamonds + alloys) and performing tests in supportive moulds a good shaping was possible
-  Different heating sources have been used
-  Densities of the samples around 85-95%
-  Certain loss of copper, therefore concentration might be higher than 50 vol%

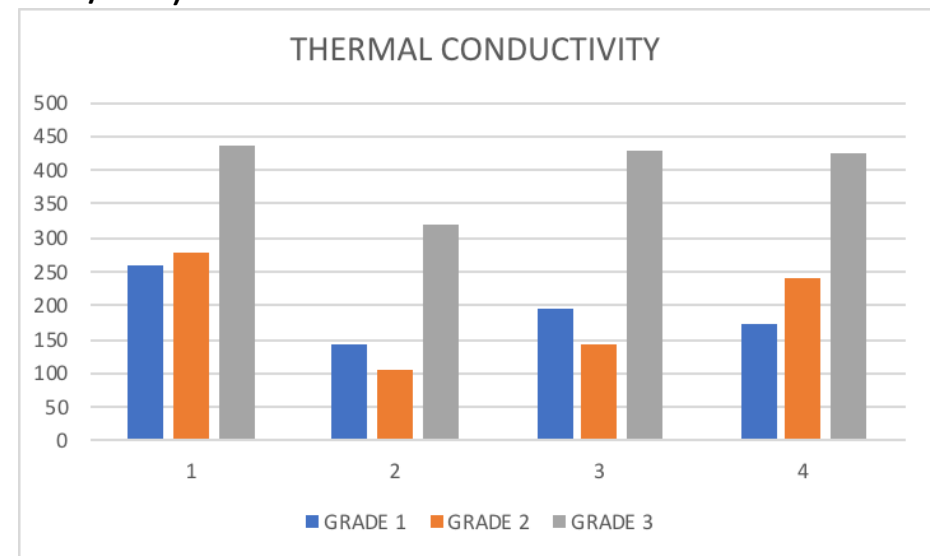





ID	Dicke	kappa	T100	Specifi heat	Archim. Density	Thermal Conductivity
	[mm]	[x 1e-6 m ² /s]	[K]	J/kgK	g/cm ³	W/mK
15	3,98	182,34	0,35	0,40	5,26	384,6
16	3,64	152,44	0,45	0,40	4,46	272,6
17	4,50	261,67	0,34	0,40	4,65	487,9

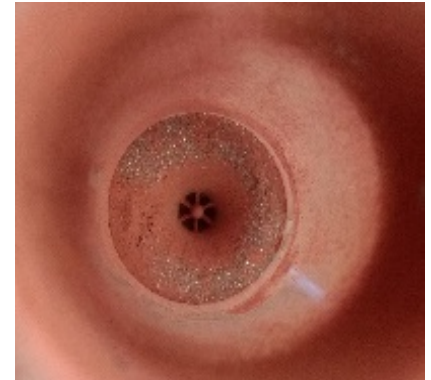


-  Several challenges to solve when using a plasma arc deposition process for the manufacturing of a metal diamond composites
-  Concept was developed to separate the different issues and to tackle them individually
-  Main difficulties: many parameters which are severely linked to each other and which result in a contradiction, e.g.
 -  High gas flow required for protection of diamonds => severe overspray observed
 -  High temperature of the melt and promote wetting => degradation of the diamonds
 -  Reduction of temperature/time with melt => less wetting/weak interface and pores
 -  Using of hydrogen to reduce metal matrix => creation of gas bubbles in the matrix
 -  High energy required to enable a good bonding to the substrate – low enough to limit the deformation/loss of shape of the substrate
 -  ...and many more

- A granulation process for highly loaded diamond contents could be established
- First small sized demonstrator parts (20-30 mm) could be fabricated. An upscaling and optimization of the process is required (improvement of density)
- A “free-form processing” with this concept was not possible, so tooling is required.
- Thermal properties are promising (>400 W/mK) with $CTE < 10$ ppm/K was achieved.

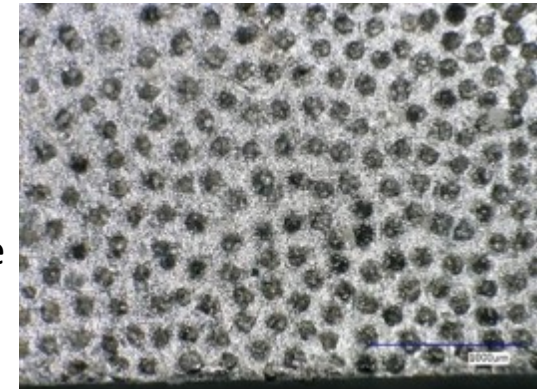
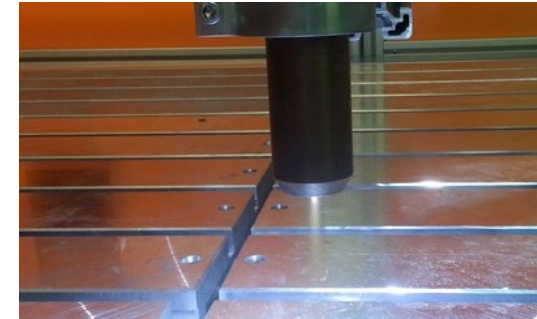







-  Development of a concept for a powder feeder allowing to feed diamond containing material in different size => meanwhile we have identified a commercial powder feeding system which is on the market available
-  For the Plasma based process new alloys have been identified which have an excellent wetting => this knowledge is used for the powder metallurgical processing
-  Additionally based on the experience a liquid phase processing concept was derived and has been applied on prototype level for electronic components => currently under evaluation



Potential commercialisation developments in the future

- Upscaling of the processing technology and demonstration
 - Main focus is to enable a fast processing for the heat sink manufacturing
 - Preparation of a plasma torch setup which allows to process pre-compacted of larger size
 - Oxidation has to be avoided, which means a setup which allows to deal with forming gas is required (encapsulated) and where the oxygen level is monitored
- Transfer of the developed compositions to the powder metallurgical manufacturing process for the heat sink preparation => application in thermal management applications (especially large structures)
 - The developed building blocks (combination of coated diamonds with alloys) allows a much faster processing of the materials
- Alternative applications might include the use the manufacturing in grinding tools => especially the arrangement



-  In general the PoC represents a good way to assess an innovative concept with a certain specific risk
-  It allowed to assess different manufacturing concepts to identify the most promising concepts for follow up activities
-  Overall administration/reporting is in a good balance, therefore we can recommend this funding scheme.
-  Suggestions for improvement are:
 -  Enable the possibility to proceed with follow-up activity (e.g. demonstration activity/"phase 2") after the proof of concept in order to increase the TRL, upscale etc.



Thank you for your attention !

**MATERIALS.
PERFECTLY.
TUNED.**

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