Challenges with application of additive manufacturing in energy sector

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Abstract. Additive manufacturing (AM) is treated as a significant contributor to sustainability due to lower energy consumption, less material usage and reduced number of wastes generated when comparing with traditional manufacturing technologies. Currently there is a lot of commercial applications of such new technology in number of industry segments. However, such sector as high voltage engineering still struggles with number of challenges when considering additive manufacturing. In products working in high voltage environment, very often, in addition to mechanical loads there are demanding conditions, as elevated temperature and presence of insulation oil or gas. This requires a special approach to printing quality of the printed structures without internal voids and in case of metals, with improved electrical conductivity. In the paper, few examples of additive manufacturing applications in area of power products have been presented, including printed transformer insulation, printed copper, and application of AM for spare parts. For each case, the main challenges have been discussed.

1 Introduction

Additive Manufacturing/3D printing is one of the most booming technologies in last decade; this refers both to printing techniques, as well as availability of the printable materials. Today, Additive Manufacturing (AM) is disrupting conventional manufacturing based on machining, casting, moulding, and forming technologies in several mature and traditional industries, e.g., automotive, aerospace etc. With such fast developments in AM technologies in recent years, the pace of AM adoption is increasing dramatically within different businesses, thanks to the advantages that AM brings with respect to building complex products, speeding up product innovation, reducing size and weight of the components with reduced waste and enabling new service business models.

Additive manufacturing landscape (printer developers, material suppliers, academia, software developers) is now very broad and the users have a lot of opportunities in selection of the most suitable printing technology and relevant materials. However, even despite such excess of possible printing options, still in most industrial applications there is a lot of challenges in fulfilment of all technical requirements. This is even more difficult in such

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areas as high voltage engineering (energy sector), where in addition to mechanical loads there are special conditions, as interaction with oil under high voltage and at elevated temperatures.

In the following chapters few examples of additive manufacturing applications in area of power products have been discussed, including printed transformer insulation, printed copper, as well as application of AM for spare parts. For each case, a number of challenges related with a new technology have been identified and discussed.

2 Case study – Transformer insulation

2.1 Currently used manufacturing process

Cellulose is a dominant material used for power transformers insulation and there is a lot of sizes and shape variants of insulation components (Figure 1). Such biomaterial is characterized by high purity, excellent dielectric strength, good mechanical strength, and ability to be impregnated with oil thus avoiding partial discharges and long lifetime at operating temperature. It is usually applied as wet sheets of electrotechnical paper (pressboard or presspahn). In case when using wet cellulose sheets (pulp with ca. 70% of moisture content) as the raw material, the manufacturing process (wet moulding) is multi-step, labour intensive and consuming a lot of energy for drying of the final component.

Thus, there is a clear need to improve the manufacturing process of electrical insulation components in terms of energy consumption, waste generation, duration, and possible automation. 3D printing has been considered as alternative manufacturing technology without moulding and drying however has required a development of suitable printable biomaterial.

Fig. 1. Examples of cellulosic components for transformer insulation.

2.2 Development of new biomaterial and printing technology

In frame of NOVUM project (The work subsidized by the European Commission Horizon 2020/SPIRE, proposal number: 768604, proposal acronym: NOVUM) initiated by ABB Corporate Research in Krakow (later continued by Hitachi Energy Research) and coordinated by VTT Research Institute from Helsinki, development of new bio-based material and suitable 3D printing technology have been explored. Number of material formulations have been developed and all technical requirements (oil compatibility, mechanical strength, and dielectric performance) have been verified to identify the most suitable printable material. The material has been based on cellulose acetate with micro-cellulose fillers [1].

2.3 Characteristics of printed samples

The benchmark samples have been manufactured at Hitachi Energy Insulation Kit Center in Lodz, Poland using traditional wet pulp cellulose. Components to be compared have been printed by Brinter company from Finland using extrusion-based technology. Figure 2 presents the same component manufactured by traditional wet pulp moulding and novel printing technology. As a positive outcome, it has been confirmed that when using 3D printing in case of electrical insulation, a shorter cycle time, reduced energy consumption, and reduced volumes of waste material can be achieved. In some areas of the printed components, however still some imperfections are observed due to quality of interface between the printed layers. This results in delamination and/or internal voids creation during printing process. Elimination of such defects is one of the key challenges. More information about that development can be found in [2].

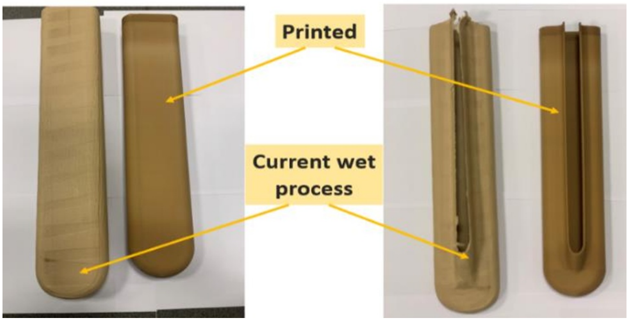

Fig. 2. Printed and moulded insulation component

Very broad material analyses have been performed to characterize the printed samples, but only selected results are presented below; in Figures 3 and 4 permittivity and dissipation factor are shown. The obtained results show high similarity between both materials. The standard technology samples have permittivity at level of 3, and NOVUM samples of 3.48. The dissipation factor is respectively 0.0077 and 0.0064.

In addition, in Table 1 comparison of electrical breakdown strength has been presented. The breakdown strength for standard technology samples is almost two times higher than the printed structures which can be the results of internal voids and not homogeneous microstructure of the printed samples.

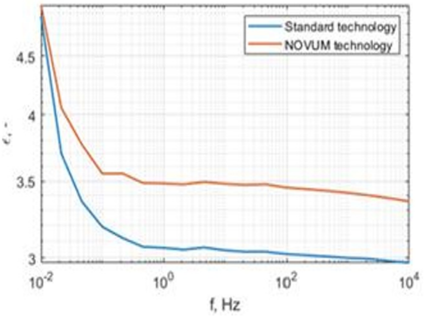

Fig. 3. Permittivity of printed and moulded component

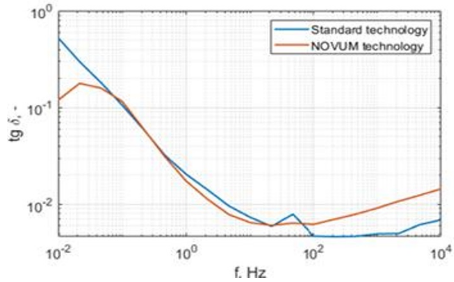

Fig. 4. Dissipation factor of printed and moulded component

Table 1. Breakdown voltage comparison

Sample	h, mm	E_{br} , kV/mm
Standard technology sample 1	2,55	>23,5
Standard technology sample 2	2,75	>21,8
Standard technology sample 3	2,41	>24,9
NOVUM printed sample 1	2,53	14,4
NOVUM printed sample 2	2,56	14,2
NOVUM printed sample 2	2,81	12,1

3 Case study – copper printing

Copper is considered as one of the most strategic resources used in the production of power products. It is estimated that the global power system in 2050 will require four times more generating capacity than today and will have to transfer three times more electricity. Also, growing consumption in other industrial sectors estimated based on e.g. automotive megatrends will result in an increase in demand for copper at the level of 4.8% CAGR (Compound Annual Growth Rate) until 2034 [3]. Therefore, more sustainable production technologies and advanced design concepts will play an important role in minimizing copper consumption, optimizing costs, and reducing waste generated in traditional manufacturing processes. In case of power products in addition to proper mechanical properties, electrical conductivity of printed components is essential.

The case study included a comparative analysis of the basic properties of printed contact elements made of pure copper (Cu-ETP) with a relatively complex shape and real dimensions (approx. 100x60x20 mm) and their counterparts manufactured using commonly used traditional methods, i.e. sand casting (SC) and subtractive manufacturing (SM). The printed components were obtained using dedicated additive manufacturing technologies using Binder Jetting (BJ) and Direct Metal Laser Sintering (DMLS), which are state-of-the-art methods used in copper printing. The analysis included comparison of electrical conductivity, hardness, yield strength and microstructural features to examine defects and was aimed at checking the feasibility of using additive manufacturing to produce full-scale copper components operating in a real device in extreme conditions, in which all phenomena accompanying mechanical contact and uninterrupted current conduction can occur at the same time.

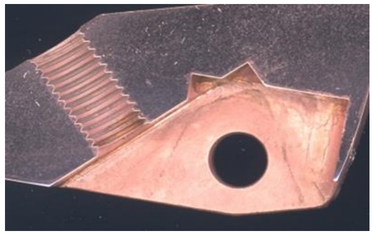

Fig. 5. Cross section of the benchmarked component (due to the confidentiality clause, only a fragment is shown)

Contact elements printed in BJ technology were made of 44um powder on an ExOne printer, printed in DMLS technology from CuCP powder on an EOS M290 printer, and contacts made using traditional methods were obtained by casting (SC) in sand moulds printed on an ExOne printer and by standard machining (SM) from a flat Cu-ETP bar H075/R280 temper material. A summary of the results of the basic properties measured on the middle sections of samples obtained by various methods is presented in Table 2.

It is clear from the results of the basic physical properties of copper components manufactured by subtractive and additive methods, which were also compared with published data, that additive technologies have made great progress over the last decade. From the point of view of applications in the energy industry, it is extremely important to emphasize the exceptionally good results of electrical conductivity obtained in DMLS technology, which are only slightly lower than the reference value expressed in %IACS. Also, in the case of DMLS technology, attention should be paid to particularly good homogeneity and no microstructural defects, which is associated with very high relative density values. Particularly noteworthy is the observed hardening occurring in the DMLS component after printing (at the material level in the H80 hardening state). In summary, DMLS technology provides a set of properties that even exceed the performance properties of components produced by sand casting.

Table 2. Material properties of components manufactured using various methods

Manufacturing method			**BJ**	**SC**	**DMLS**	**SM**
Oxygen content, ppm			62	89	253	261
Specific density, g/cm³			7.58	8.72	8.83	8.86
Yield strength, $R_{cp0.2}$, MPa			71.0	85.1	169	258
HV1	Average		27.8	41.3	78.2	92.8
	Standard deviation		1.6	4.5	3.7	2.5
Conductivity	Average	MS/m	28.05	56.45	57.12	58.56
	Standard deviation		0.37	0.08	0.19	0.08
	Average value	%IACS	48.4	97.3	98.5	101.0

4 Case study – Additive manufacturing for spare parts

Additive manufacturing has gained attention for its potential in providing spare parts due to its ability to shorten lead times and reduce storage costs [4]. AM can be economically attractive, particularly for low volume spare parts production as it provides flexibility in producing spare parts as and when needed, unlike conventional manufacturing, wherein high volumes and therefore, higher inventories are needed, to recoup high initial investments in tooling.

Advantages of AM for spare parts manufacturing as well as current supply chain management challenges led us to consider a case study for investigating the benefits and challenges of this technology for spare parts management. Therefore, several spare parts from high voltage (HV) service unit have been considered with different level of complexity, size, and geometry. Figure 6 shows one of the smaller parts printed with Direct Metal Laser Sintering (DMLS) and applied post processing to achieve the required surface roughness and Figure 7 demonstrates manufacturing of a larger part with sand mold printing and casting.

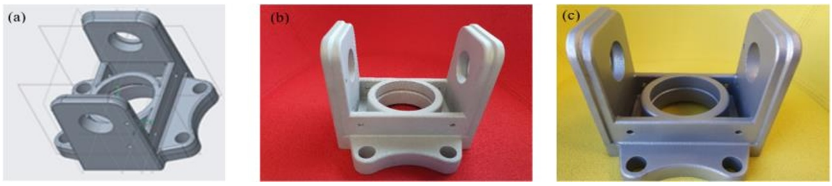

Fig.6. a) 3D model of candidate spare part, b) Printed parts by DMLS method and AlSi10Mg alloy, c) Part after post processing by additive-formulated consumables method.

Fig.7. a) Printed sand mold by BJ method, b) Casting process of aluminium spare part, and c) part after casting and machining

5 Conclusions

Additive manufacturing can bring number of benefits, however in such applications as high voltage power products, number of challenges can be identified. These include:

- In case of electrical insulation components, 3D printing without internal voids is very important and extensive research on optimization of the printing parameters is required,
- For printed copper, the electrical conductivity is the most important parameter, and therefore a main focus is placed on selection of best copper powder and printing technology,
- Significant numbers of spare parts in HV service are made of aluminium alloys due to required electrical conductivity, mechanical properties, light weight, and low cost. Printing of aluminium requires additional post-treatment aiming reduction of a surface roughness and an improvement of the electrical conductivity.

References

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