Feasibility study 3D Printing of electric motors

The central aim of this research project is to investigate and to test the extent to which the technology of additive manufacturing is suitable for the production of rotors for encoderless regulated permanent magnetic synchronous machines (PMSM).

1. Objectives

Additive Manufacturing (AM) technologies offer three key advantages towards conventional manufacturing methods for electric motors. First advantage is, that the leakage paths of rotors can be designed so that they comply with the mechanical constraints and at the same time have a low magnetic conductivity. Therefore the design of the rotor is no longer limited to a two-dimensional sheet section. Moreover a lightweight optimization can be carried out. The second advantage is the absence of a punching tools impact which implements uncertainties of the magnetic properties at the cutting edge. Because of the absence of cutting edges AM technologies offer a significantly better prediction and reproducibility of the magnetic properties. The third advantage is the fact, that additive processes such as selective laser melting (SLM) generate components based on a powdery raw material. In principle it is possible to use additive manufactured soft magnetic composites (SMC) or other magnetic powder materials.

2. Procedure

The possibilities of a lightweight design with a low moment of inertia as well as a high tensile strength of the additive manufactured material will be pointed out. A useful material with ferromagnetic properties will be identified and the usability of SMC materials will be investigated. Specimens of the chosen material will be developed and produced with AM to investigate the resulting mechanical properties like the yield strength, the ultimate tensile strength and the hardness, as well as the electromagnetic properties like the coercitivity, the electrical conductivity and the permeability. Based on the results of preceding experimental investigations an innovative lightweight rotor design for a PMSM prototype machine will be developed, manufactured and compared to a conventional rotor design.

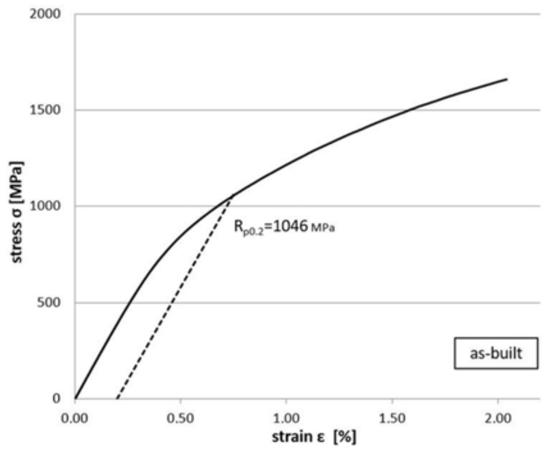

Figure 24: Results of tensile tests on H13 specimens

3. Latest results

The most suitable material for the investigations was the H13 material because of its ferromagnetic behavior and high availability. SMC material was not suitable for the SLM process because of its plastic cladding. The tensile strength and elongation at rupture of the solid material H13 (1.2344) were determined by tensile tests on R2 specimens. The geometry of the R2 specimens is based on the DIN EN IS0 6892-1 standard. The results are shown in Figure 24. The Vickers hardness varies depending on the distance of the building platform between 670 HV5 and 620 HV5. Higher layers in the building space show a higher hardness than lower layers. This results from heat dissipation through the lower layers which affects the heat treatment of the lower layers. For the investigation of the electromagnetic properties, ring cores were produced with an outer diameter of 62 mm and a cross-section of 6 x 6 mm. To identify the magnetic properties of the AM material H13, the ring cores were wound with a primary excitation winding and a secondary measurement winding to apply a magnetic field and measure the average magnetic flux density. The results showed a hard magnetic material behaviour with a poor permeability. These poor magnetic properties could be ascribed to a martensitic microstructure with parts of austenite. Heat treatment was performed to improve the magnetic properties with a ferrite-pearlite microstructure. The heat treatment resulted in a significant improvement of the permeability. The design of the PMSM was optimized in terms of a production-ready lightweight design. In order to reduce the weight while maintaining strength, cavities and lattice structures were implemented into the rotor. This lowers the moment of inertia of the rotor about 23%. In addition, gaps and holes were provided to remove the unplasticized metal powder in the area of lattice structures and cavities. The produced and mounted rotor is shown in Figure 25.

4. Outlook

The results show that the magnetic properties of H13 can be significantly improved by a heat treatment, so that its permeability nearly reaches the level of SMC materials. Finally, an improved new rotor with a lightweight design was developed and manufactured for a prototype machine. Compared to the conventional design, the mass of the rotor is reduced by 25% and the moment of inertia decreases by 23%. This leads to a shorter acceleration time by 23.2%. Additionally, sensorless control was made possible for this machine by means of rotor coils. Future materials for AM with better magnetic properties will unlock the full potential of the additional degrees of freedom in the rotor design. The results clearly demonstrate the great potential of additive manufacturing in electrical engineering applications. For future studies, more investigations of the electromagnetic behavior of additively manufactured materials are needed. Besides, realizable function integration like cooling effects or lightweight designs are required to establish additive manufacturing as a standard process in industrial process chains.

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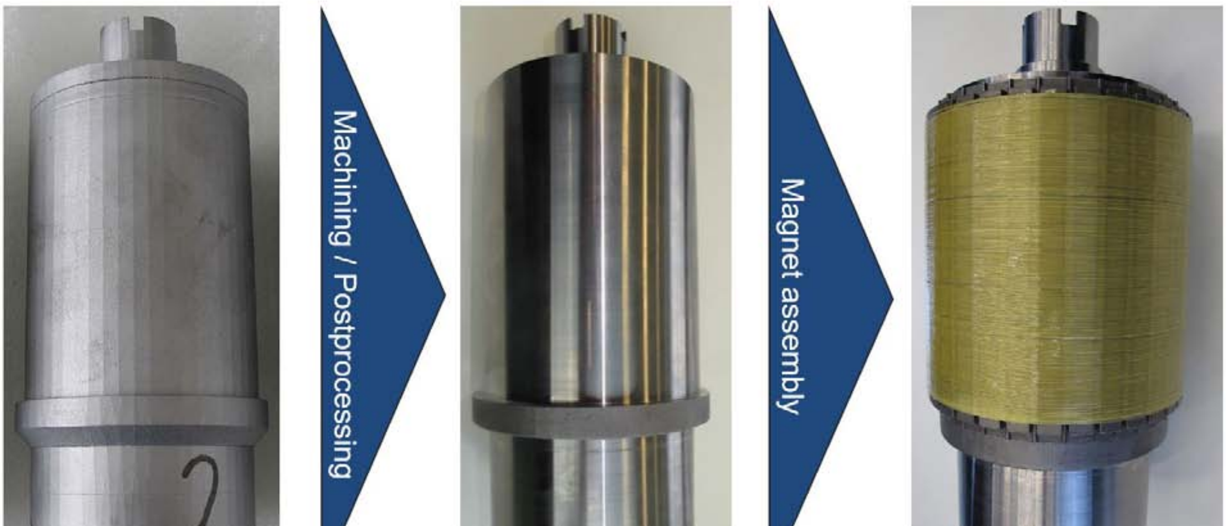

Figure 25: Additive manufactured rotor and after treatment