Standardization of test particles by trial-based approximation of the damaging potential of manufacturing swarfs

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Abstract

Particulate residues originating from manufacturing and assembly processes can cause severe incidents in automobile powertrains or safety-relevant modules. Robustness validation and tribological studies require synthetic test contamination to imitate the particulate residues. A collaborative research project was started to evaluate whether such particles could be produced with high reproducibility and if they would reveal sufficient damage potential. To enable future mass production micro powder injection molding (MicroPIM) was chosen as manufacturing process with the lowest tolerances and best reproducibility. For this purpose micro suitable feedstocks containing 42CrMo4 steel powders had to be developed. Additionally, micro mold inserts incorporating free-formed surfaces had been used for the first time. The damage potential of the test particles was evaluated based on trials using journal bearing and shift valve test rigs. Furthermore, test particles and particulate debris from assembly processes were analyzed by light microscopy and micro computer tomography in order to check the fit of characteristics.

1 Objectives

Tiny metal swarfs and flakes occurring as material debris during subtractive manufacturing or assembly processes can cause early failures and severe results for car passengers. This phenomenon is not limited to automobiles, but also wind turbines and all moving or rotating shafts in guiding structures. For comprehensive investigation and approximation of the wear and damaging potential standardized micro-sized particles are required. Therefore, four research institutes and companies started an R+D project founded by the Federal Ministry of Economic Affairs and Energy (BMWi).
Main goal of the collaborative research project was to develop a draft for the definition of standardized test particles. For this purpose, it was necessary to evaluate whether test particles of sufficient reproducibility could be produced and if they would reveal significant damage potential.

2 MicroPIM of test particles with free-form geomtetries

Based on microscopic analysis of various real manufacturing swarfs, five different designs of geometrically defined test particles, e.g. octahedron or twin-pyramid, were developed. Maximum size of each design was 1mm in green state, i.e. all samples underwent further shrinkage during sintering. Additionally, a free-formed design derived from real swarfs was developed subsequently to 3D characterization of the original production swarfs.
For manufacturing two different techniques, namely micro milling and micro powder injection molding (MicroPIM), were investigated. Detailed descriptions of the latter can be found, for example, in [1-3]. Concerning MicroPIM, it has to be mentioned that feedstocks containing fine 42CrMo4 steel powders were applied first time. Additionally, micro mold inserts incorporating for the first time free-formed surfaces were designed, manufactured, and used for PIM trials.

Due to space reasons the focus of this contribution was led on MicroPIM of free-formed synthetic test particles:

For this purpose, a suitable feedstock based on the GoMikro binder system of KIT - which is generally spoken a mixture of polyethylene, paraffine wax, and stearic acid - had to be developed. Ad powder, a commercial 42CrMo4 (1.7225) type provided by Sandvik Inc. was used. Measurements at KIT showed a d50 of 5.7µm and a specific surface (BET) of $0.25 m^2/g$. Based on previous MicroPIM experience powder loading was kept constant at 63Vol%.

Injection molding experiments were performed on a Battenfeld Microsystem 50 machine **(Figure 1)**. It was equipped with a standard MicroPIM tool whose core section carried mold inserts which were developed especially for this project using a commercial software routine for simulating the filling and cooling steps of the process **(Figure 2)**.

Figure 1: The Battenfeld Microsystem 50 injection molding machine used for replication of the artificial swarf samples.

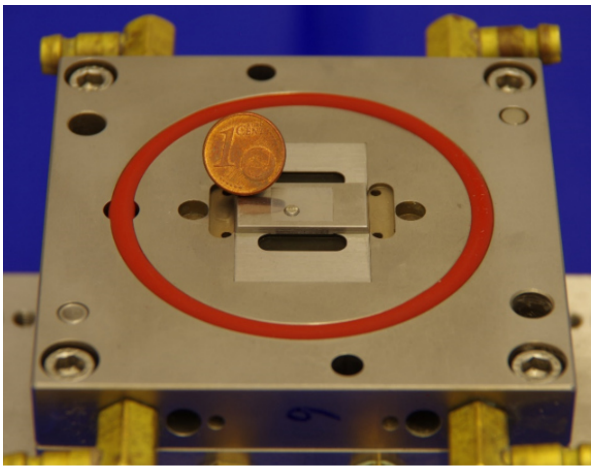

Figure 2: View on the parting plane of the special molding tool. Note the circular rubber sealing required for evacuation prior to injection.

The whole machinery arrangement was characterized by two specialities, namely the tool evacuation which is necessary to avoid burning of the material during injection, and the so-called variothermal temperization. This means that the core section of the tool is heated up to accelerated temperatures to avoid early freezing of the injected feedstock. Immediately after completion of the filling step the core section was cooled down to enable save ejection of the molded parts. Such variothermal procedure reveals particular advantages in case of metal injection molding due to the increased thermal conductivity of feedstocks highly filled with metal powders thus usually resulting in premature freezing during injection. For example, here the tool temperature for injection was increased up to 60-95°C and subsequently reduced to 20-25°C prior to demolding. Further parameters to be mentioned were the material temperature of approx. 165°C and the injection pressure of 1350bar. An example of such a molded green body as visible in light microscope is given by **Figure 3**.

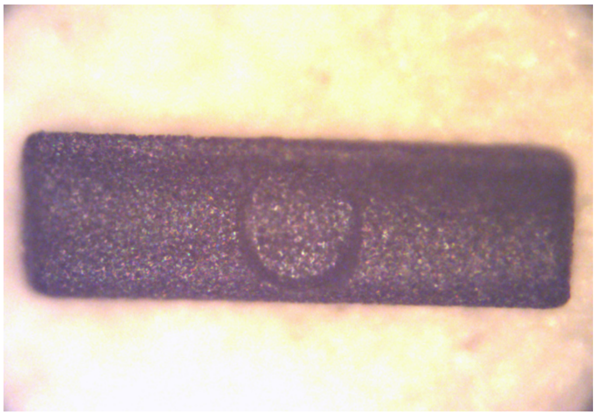

Figure 3: Green body produced by the injection molding process described above. Length approx.. 1,170µm, width approx.. 340µm. Note the circular marking in the middle caused by the ejector pin.

Debinding was performed by a two-step procedure, namely fluid dissolution in hexane followed by a thermal debinding step which was incorporated in the upheating ramp of the sintering procedure. The entire thermal process conduct is shown by **Figure 4**.

Density of the sinterered samples as measured by He-pycnometry was $7.02 g/cm^3$ which corresponds to theoretical density of 99.7%. These finally compacted parts **(Figure 5)** were sent to the other project partners for further investigation.

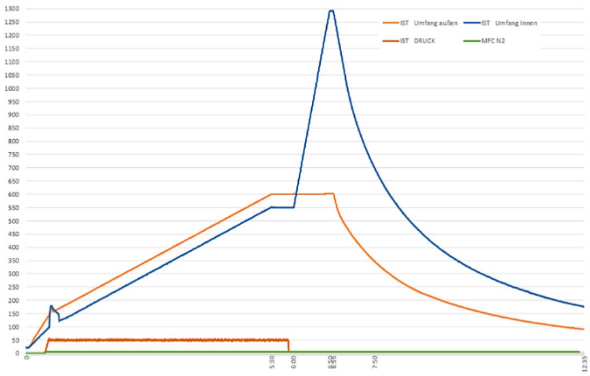

Figure 4: Diagram of the combined debinding and sintering treatment. Upper curve: temperature in the sample chamber of the furnace. Maximum temperature was 1300°C hold for only 5min due to the tiny dimensions of the samples.

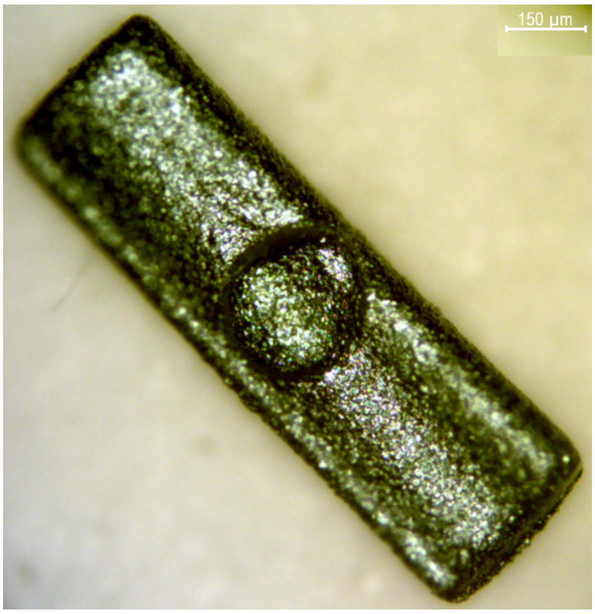

Figure 5: Finally sintered micro test particle.

3 Results

The damage potential of the test particles was evaluated based on tests using journal bearing and shift valve test rigs. On both test rigs, the particles were supplied to the test specimen via the supplied oil. The journal bearing test bench consists of a connecting rod implemented with slide bearings which applies a motor load profile to a rotating shaft. The occurred friction energy is divided into hydrodynamic and solid friction of which the solid friction disappears due to the progressive inlet wear. This situation will be disturbed immediately by feeding the test specimen with particles. The solid friction increases due to different damage mechanism, e.g. abrasive wear while the particle scratches the bearing material, temperature increasing concomitant with bearing clearance shrinking and viscosity degradation which causes in sum higher stress. Finally, the bearing stands it by the so called self-healing process or it fails by scuffing. The survey of the test parts and the behavior during the test is used for the rating of the damage accumulation of the particles.
The damage mechanism at the sleeve valves are less defective but with a similar damage scale. The particle blocks the valves motion so that a chain reaction of failures impairs the function of the gear box up to a not possible gear changing. For the determination of the damage accumulation the survey of the test parts is used.

Furthermore, residue contamination had been investigated whether it shows typical characteristics, which then could form the basis to define particle shape categories which are representative for the manufacturing processes or a group of similar components. Natural contamination consists of uniquely shaped particles, which cannot be reproduced nor used for cause and effects analyses. The abstraction of the particle shape was necessary to create synthetic test contamination for standardized test runs.
As a result of the investigations, the particles did not show any dependencies on the manufacturing processes or components. However, four shape categories had been identified, which are a) burr-alike with a high aspect ratio, b) swarf-alike with spiral runners, c) compact and flattened with low aspect ratio and d) irregular shapes.

4 Acknowledgement

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5 Literature

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