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A reference artefact to evaluate the metrological performance in the quantification of raising surface defects on manufactured surfaces

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Abstract

The identification and the geometrical quantification of surface imperfections resulting from the manufacturing process are relevant for both ensuring part conformity and process control, and additionally are of great interest for in-line applications. In many industrial contexts surface imperfections represent an important measurement requirement and a variety of measuring principles and systems can be used. Therefore, appropriate methods for evaluating the metrological performance of measuring systems are required to support equipment selection and monitoring. The paper presents a novel reference artefact (i.e. material measure) that is specifically designed to test the metrological performance in the geometrical characterization of outward surface imperfections.

Surface defects; metrological performance; zero-defect manufacturing

1. Introduction

Surface imperfections on manufactured parts are in most cases undesirable, and they are therefore regarded as surface defects. Understanding if manufacturing processes generate such defects is then essential, and many different approaches and measuring techniques are available for on-line or off-line inspection [1]. Surface defects are relevant because they reduce the functionality of the part (e.g. mating performances) or have consequences in the application (e.g. reduce fatigue life). Surface topography modification due to running-in of mechanical parts, for example, is mainly attributed to removal of outward asperities, resulting in a higher contact area ratio. In manufacturing hip implants, it is important to reduce peaks that protrude from the surface because detrimental to wear resistance. Outward surface defects can also be detrimental in mating of parts and causing difficulties in assembly. Imperfections occurring on functional surfaces of dies and molds are also problematic, because they may transfer to the replicated part, particularly in the processing of polymers and in die-casting. Such replicated imperfections may have further consequences. For example, hot cracking of dies in casting of aluminum may result in burrs raising from the die-cast part surface to a level (in the order of 0.2 mm) that can be damaging other parts, e.g. perforating insulation of small electrical cables in connection with vibrations [2]. In more general terms, failures on dies and molds are an important aspect with economic impact in the order of hundred billions US dollars [3].

Defects with heights in the range 50-500 µm can be quantified using different measuring principles that are common in surface metrology (e.g. confocal microscopy, focus variation) or more often used in coordinate metrology (e.g. fringe projection, laser triangulation). Related measuring systems are tested against calibrated artefacts [4, 5, 6] using procedures described in relevant standards (e.g. ISO 25178 and 10360 series). Unfortunately, it may be difficult to derive information on the system performance when measuring surface defects having a specific morphology and dimensional range. Additionally, for in-line applications it is highly desirable to detect defects over the entire surface of the manufactured part, and this may have a size in a much larger scale. The aim of the on-going work documented in this contribution is to investigate on procedures to evaluate the metrological performance of a given measuring system when measuring the size of an outward surface defect. More specifically, the design of a reference specimen prototype is discussed and presented.

2. Case study

Surface defects represent a challenging scale problem, since the dimensions of the defects totally differ from the size of the manufactured part where they are located. Ideally, the entire physical part should be measured shortly after manufacturing and fully represented by a digital model having all details of interest, including surface defects. The model is then processed to concurrently perform GPS verification, CAD comparison on form deviations and surface imperfections analysis. Since there is no general solution to this problem, a case study can be helpful to identify the needs.

The selected case study is the inspection of surface defects on an aluminium part for automotive applications, manufactured by high-pressure die-casting. The max height of single raising surface defects is relevant for maintaining full functionality of the product [2].

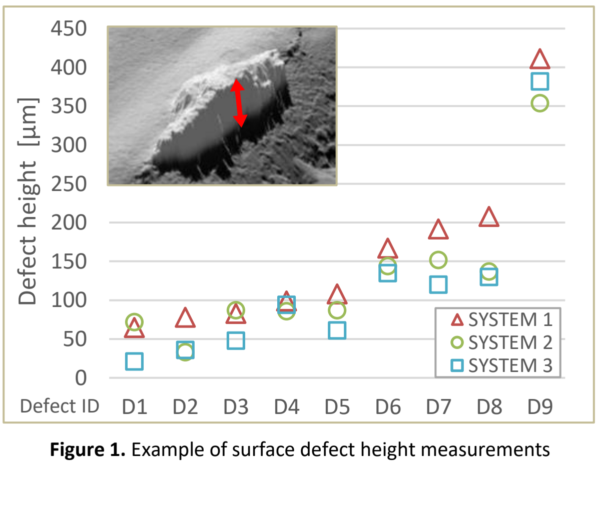


Figure 1. Example of surface defect height measurements

Fig.1 shows an example of results obtained using three different measuring systems to digitise a reference part, while data processing (i.e. measurand definition, filtering and evaluation method) was identical as previously described [2]. The significant differences observed in results are mainly attributed to the different measuring performance, however they are also strongly affected by the different morphology (e.g. overall shape, aspect ratios) of the specific defects, while little correlation is observed with defect heights. The case study highlighted, in particular, that the specific defects morphology affects the selection of optimal system configuration (e.g. measuring principle, field of view, resolution). To further investigate the measuring performance and to reduce the test uncertainty [7], a reference specimen was designed having geometrical features similar to relevant surface defects.

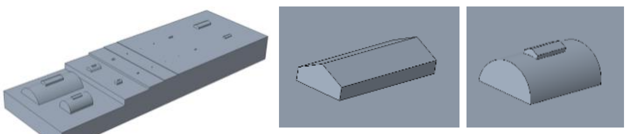
3. Reference artefact simulating raising surface defects

The proposed material measure aims at high similarity with the raising surface imperfections on aluminium die-castings, with a predominant dimension of the imperfection parallel to the surface [2]. The raising is reproduced by a prismatic functional element with rectangular base (i.e. defined by width and length) and the upper portion presenting a cusp with triangular profile. The proportion between length, width and height characterizes the similarity to typical defects as extrapolated from the case study. The dimensional characterization of the defects on the aluminium specimens highlighted a typical ratio between width and length (W/L= 0,4 ±20%), and height and length (H/L= 0,2 ±15%). Thus, the proposed artefact element dimensions are based on the observed ratios (H; W=2*H; L=5*H), using height as entry-data. The dimensions are scaled down on eight levels, resulting in eight functional elements (A to H) and summarised in Table 1.

Table 1. Nominal dimensions of artefact functional elements (in µm)

Element	*Height*	*Width*	*Length*
A	20	40	100
B	30	60	150
C	40	80	200
D	80	160	400
E	160	320	800
F	320	640	1600
G	640	1280	3200
H	1280	2560	6400

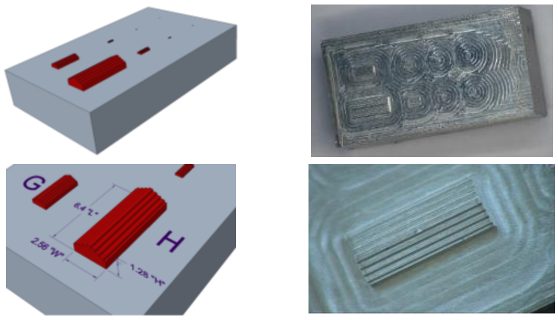
An initial concept design presented two evaluation areas. Eight scalar elements are distributed over a flat surface (Fig.2.a), which is the reference for the height evaluations. The same eight raising elements are also distributed over eight cylindrical surface portions, proportional to the element dimensions (Fig.2.b). These elements would test the evaluation of imperfections on round edges of castings, corresponding to notch stress points on dies, relevant for fatigue life control.



(a) (b)

Figure 2. Early concept: elements on flat (a) and round surfaces (b)

Different micromanufacturing technologies were analysed considering the production requirements in terms of dimensional accuracy and surface finish. Micro milling was identified as an adequate solution; however, the initial concept design was adapted to improve its manufacturability by micro milling using standard tooling. In particular, the rounded and tilted surfaces were discretized in a stair-like design (Fig.3.a) that represent a deterministic simulation of surface defects having different actual morphology however approximately the same overall dimensions. The eight different elements were manufactured by using an ultra-precise micro milling center (Kugler, Micromaster 5X) over a flat reference surface, applying a 2 ½ D machining strategy. The workpiece material was an aluminium alloy (7050-T7451) and the choice of both the micro milling tools and process parameters were selected to optimize the quality of the final artefact in terms of surface roughness and feasible features dimensions (Fig.3.b).



(a) (b)

Figure 3. Final design (a) and prototype (b) of the specimen

4. Outlook

The proposed reference artefact includes eight simulated surface defects of different size. Next activities will include how to calibrate and then use it for evaluating the actual metrological performance of different measuring systems relevant for the application and for supporting the equipment selection process.

Further optimization of the prototype is on-going and will include surface modifications to mimic the reflectivity obtained by high-pressure die-casting. This is relevant for aligning the material measure surface properties to the real application aiming at in-line measurements e.g. without coating the surface to make it collaborative. Alternative manufacturing process are also under investigation. The elements geometry can be further optimized too. The vertical lateral faces are partially consistent with the real defect, and may entail constraints in calibration procedures. Moreover, on other consistent artefacts, the elements range can be extended according to the defects size to be tested.

5. Conclusions

The paper highlights the requirement of dedicated material measure for the metrological performances evaluation of measuring systems for the in-line quantification of surface defects. A concept design and a prototype are proposed, as basis for future developments.

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