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Study of automated procedures for surface defects analysis on die-cast components by using fringe projection systems

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Abstract
Quantitative surface defects analysis in high-pressure die-casting is relevant both for quality assurance of part functionality and for monitoring the functional surfaces of dies. Advanced optical techniques for digitization of parts enable fast identification of surface irregularities and their measurement. The use of automation and appropriate enclosures enables quality control operations directly in the manufacturing environment, increasing measurement repeatability, reducing inspection time and direct labour resources. The paper reports on a case study and illustrates the implementation of a fringe projection system for the analysis of surface defects on high-pressure die-castings, including the development of automated evaluation routines.

Keywords: surface defects analysis, high-pressure die-casting quality control, fringe projection system, in-line metrology

1. Introduction

Nowadays, the use of coordinate measuring systems based on optical principles is well established in the manufacturing industry quality assurance. The use of automation enables in-line control and feedback-based process optimization [1]. Among many applications, the in-line detection and measurement of surface imperfections is a challenging task. The purpose of the present study is to assess the automated use of fringe projection system (FPS) to detect and analyse surface defects on aluminium alloy high-pressure die-castings. In case of no subsequent surface machining processes, the evaluation of raising defects on cast surfaces is mainly relevant for part functionality assessment (e.g. handling, mating, and assembly). Furthermore, the dimensional measurement of raisings irregularities enables the monitoring of dies functional surfaces i.e. casting burrs resulting from the replication of cracks on dies due to thermo-mechanical fatigue [2]. For this reason, in-line inspection of surface defects enables preventive maintenance [1] and continuous monitoring of casting equipment.

2. Case study

The specimen used for the investigation is an aluminium alloy case for automotive electrical PCB, manufactured by high-pressure die-casting process by the company Alupress AG. The evaluation of single raising surface defects is mainly relevant for two reasons. During the die-casting process, the presence of cracks on dies functional surfaces cause raising defects on the replicated parts. These cracks, mainly due to thermo-mechanical fatigue, are located in the dies regions of stress concentration and notch effects (e.g. fillet radius) [2] The evaluation of the single raising defect geometry on the replicated part provides a backward information for analysing cracks propagation on dies, enabling monitoring of dies conditions for related maintenance actions (e.g. repair or replacing) [3]. For part functional conformity, raising defects on the internal surface of the case may affect the integrity of the PCB components and electrical cables. This problem is related to the location and dimension of the defect in respect to the position of the PCB in the final assembly. According to these functional requirements, the specifications identified for raising defects typically include the two measurands illustrated in Fig.1(a): A) absolute height in normal direction to the surface, relevant for the evaluation of cracks propagation; B) asymmetric height in reference to a datum surface, selected based on the position of the PCB. The tolerances are differentiated for both measurands in relation to the specific part internal surfaces, illustrated by different colours in Fig.1(b). With reference to the case study, the most restricted tolerances are of 0,2 mm for absolute height A and 0,1 mm for the asymmetric height B.

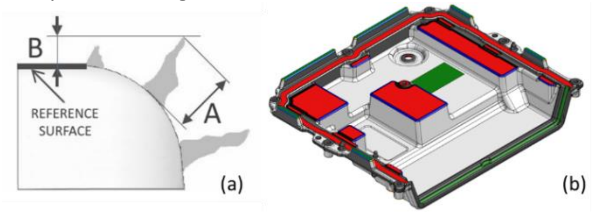

Figure 1. Measurement requirements (a) and tolerance-related areas (b)

Different measuring solutions have been investigated to characterize the defects geometry and obtain reference measurements to evaluate the FPS performances and suitability for the surface defects analysis. Tests were conducted involving tactile (e.g. stylus profilometer) and non-contact methods (i.e. confocal microscopy, focus variation). Optical profilometry with focus variation measuring principle represented the best compromise between structural resolution, accuracy in surface reconstruction and acquisition time [4]. Moreover, the point-cloud density and data format allowed an evaluation procedure highly repeatable on a given FPS data set, by using the software GOM Inspect [5]. According to both measurement requirements, the geometrical characteristics of interest were constructed and measured on the dataset acquired by focus variation. The FPS performances evaluation has been based on the comparison of measurement results obtained for the asymmetric height B, which is the most challenging task.

3. Surface defects analysis with fringe projection system

The investigated FPS is a GOM Atos Capsule featuring a robotic arm and a rotary table. The use of an automated solution allows obtaining the highest repeatability [6] and, for the purpose of the study, it was consistent to test the FPS directly on the automated process. The system was equipped with a sensor resolution of 12 million of points per scan and interchangeable optics that allow to variate the measuring volume. A smaller measuring volume allows a higher density of the point-cloud acquired during the scan, but it also entails a higher number of scans to cover the full component surface [6]. Based on the measurement requirements, two volumes were tested: MV120 (120x80x60 mm) and MV200 (200x140x140 mm). For enabling the registration of different scans, markers were placed on the part surfaces. Despite their small dimensions, the markers application affects the morphology of the surface and hides a small area on the component [7]. To limit the risk of hiding relevant surface defects, markers were distributed over non-functional flat surfaces that represented the less restrictive tolerances. The part surface reflectivity was considered and different tests were performed. Best performances were obtained by using the reflex detection setting for the FPS [5]. This application allowed the acquisition system to detect different degrees of reflectivity of the component surface and to consequently adjust the exposure time on each zone of the workpiece in order to avoid a non-optimal data acquisition. The study involved two specimens. Each part acquisition was repeated three times for each FPS configuration. The resolution obtained by using the measuring volume MV200 was not sufficient to digitize surface irregularities, and the related data sets were not further processed. The MV120 point cloud resulted more detailed and was further processed with GOM Inspect software. The identification of defects location was performed using the GOM Inspect tool named Surface Defects Map [5], based on local curvature deviation analysis. Defects geometries were evaluated consistently with the procedure adopted for the optical profilometer data set. The entire procedure was repeated three times and the average value of the asymmetric height B results was compared to the reference measurement results obtained by using focus variation.

4. Data comparison and method validation

The comparison between FPS and focus variation measured values showed an average deviation of -0,028 mm (±0.006 mm std. error 2σ). The results highlighted that the heights measured with the FPS were systematically smaller than the reference values, because of the smoothing effects resulting from FPS lower structural resolution and reconstruction accuracy [6]. Nevertheless, the obtained results were regarded as fully satisfactory for the intended use. The implemented FPS was able to detect and evaluate defects quantitatively, and the smoothing effect on the defect height was acceptable related to the most restrictive tolerance. Moreover, the tool Surface Defects Map [5] successfully enabled the identification of all the defects of interest on all the acquired dataset. Based on these results, the FPS procedure was defined acceptable and the possibility of automation further investigated.

5. Automated procedure for point cloud processing

The surface defects detection and evaluation procedure was implemented using the scripting tool of GOM Inspect. Automated procedure for point cloud processing enables high measurement repeatability and reduced inspection time[7], limiting interaction between operator and measuring system and enabling application directly in the manufacturing site. After the part acquisition, a global best-fit is used to align the scanned point cloud of the real part on the nominal CAD model. The evaluation procedure is built on the nominal data and then transferred to the real point cloud based on the alignment. The tool Patch Compound from CAD is applied to construct local single surfaces by combining one or more surfaces of interest. This tool allows the identification of the areas with specific tolerance range, to enable final part conformity verification. In sequence, the tool Surface Defect Map enables the defects detection and the evaluation of the absolute height of the defects. This specification affects both flat and curved surfaces with different tolerance value from area to area (Fig.2.a). The asymmetric height is then evaluated for the defects located on specific areas previously identified on the nominal model (e.g. fillet radius). Based on the alignment, the required reference planes are extracted from the real part point cloud and the normal directions are used to calculate the defect projected height (Fig.2.b). The values obtained by using the automated procedure are compared to the absolute and asymmetric tolerance values, and a coloured deviation map shows the results.

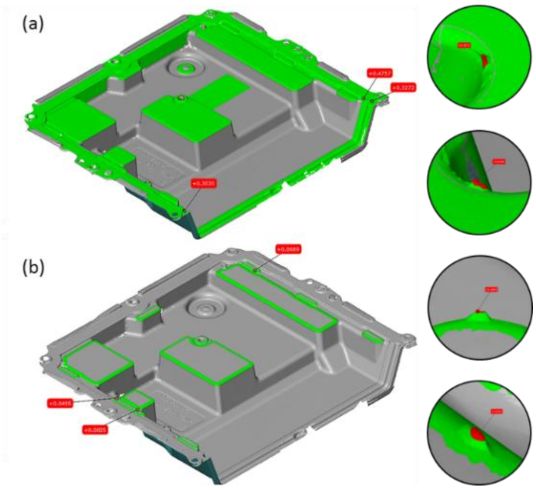

Figure 2. Measurement requirements (a) and tolerance-related areas (b)

6. Conclusions

The case study demonstrated the feasibility of automated detection and quantitative evaluation of surface defects on die-castings parts using fringe projection systems. Task-specific metrological performances were investigated and the fulfilling configuration was identified in relation to measurement requirements. Automated procedures were tested and applied to reduce inspection time and to enable in-line control directly in the manufacturing environment.

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