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Technical note

Quality inspection of metal surfaces by diffractive optical element-based glossmeter

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Abstract

Planar, convex and concave metal surfaces were produced by utilizing finishing processes that are exploited in the production of tools for plastics injection molding. A novel glossmeter, the so-called diffractive optical element-based glossmeter (DOG), was used for the inspection of the gloss of the surfaces. The Society of the Plastics Industry (SPI) A1 standard, which has the lowest surface roughness of such standards, served as a reference for the success of the finishing process. The results show that by using DOG we can gain local microscopic and macroscopic information on the gloss and its variation. The DOG is sufficiently sensitive to detect small gloss variation as well as the texture of the surface, e.g. anisotropy in surface marks. Some of the surfaces in this study have a higher surface quality than the A1 surface.

Keywords: Gloss; Metal alloys; Plastic molding

1. Introduction

Injection molding of plastic products is an important industrial sector. There is a very wide variety of plastic products, and they be found in mobile phones, health care facilities and cars, to mention only a few. To obtain high quality in plastic products the injection molding process has to be optimized. One critical factor is the metal tool that is used in injection molding. Due to the high number of moldings the tool is subject to wear. We have developed a method and a sensor to estimate the wear of the tool [1] indirectly by measuring the change of local gloss (gloss is defined in ASTM and ISO standards) using diffractive optical element-based glossmeter (DOG) [2].

The advantage of such a novel glossmeter is that a linear relationship can be found between the signal and the number of moldings on the insert tool based on readings taken on the plastic product. DOG readings indicate the progression of the wear of the tool.

Optical inspection of the gloss of plastic products in industrial environments can be realized by using DOG. However, if we want to manufacture as plastic products of the highest quality, the condition of the tool has crucial importance. The wear of the tool depends not only on the history of the molding process, but also on the initial quality of the new tool. Consequently, the surface finishing of the tool is critical to the quality of the plastic products. Thus, there is also a strong need to measure the success of the surface finish of the tool. Unfortunately, the tool usually takes a complex shape and therefore it is an overwhelming problem, e.g. to measure the surface roughness of such a tool. Using a mechanical diamond stylus is impossible because the contact nature of the stylus damages the tool. In addition, employing a laser stylus, which is a good device because of its non-destructive measurement mode, is questionable due to its high price and problems related to the stability of the system, e.g. robotics, if the laser stylus is expected to operate immediately after the molding cycle for tool inspection. Our object is to develop the DOG device in order to utilize it for the on-line inspection of the gloss of the tool itself. However, the first step is to determine the applicability and sensitivity of the DOG in inspecting the gloss of various metal surfaces finishes that are frequently used in injection molding tools. To do this we manufactured 48 different metal surfaces that take planar, convex

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and concave shapes. These samples resemble the Society of the Plastics Industry (SPI) standards, which are frequently used in estimating the success of the surface finishing process of the tools. We show that by using DOG it is possible to obtain local and average information on the change of the gloss from such samples. The sensor is very sensitive to local gloss. Finally, we observed that the gloss (quality) of some of the present samples can be higher than that of the smoothest SPI metal standard due to the advanced finishing processes developed for the manufacture of injection molding tools.

2. Samples and experimental procedure

The samples were steel alloys having different concentrations of C, Cr, Mo, Ni, V and Si denoted as M0–M3 and W4–W6 (see Table 1) that are suitable for plastic molding tools. Planar concave and convex surfaces were machined by different finishing processes including grinding, wire electrical discharge machining (EDM), sink EDM and high speed machining (HSM). The goal of the test sample production was to obtain surfaces that have a higher gloss than SPI standards. This was to optimize the time for surface finishing and the process so that the highest possible quality surfaces were realized. As will be shown below, the goal of high surface quality was achieved in the case of some samples. The present surfaces can be used for the same purpose as those meeting SPI standards. However, samples of a higher quality than the smoothest SPI metal standard (namely A1) can be used to inspect smoother surfaces with higher gloss in the sense of conventional visual inspection.

The theory behind the imaging properties of the diffractive optical element, which is the crucial part of the sensor, has been explained in detail in reference [3]; therefore, we briefly explain the main characteristics of the element. It is a binary amplitude type computer-generated hologram designed to produce a 4×4 light spot matrix when reconstructed with coherent laser light. The element was produced using an electron beam writer. The principle of the DOG can be seen in Fig. 1. The HeNe laser beam was focused using a lens on the sample surface. The diameter of the beam waist was 15 μm, and thus the lateral resolution of the DOG was 15 μm. Using DOG the gloss was obtained by scanning the object surface and collecting image data over the scanned area. The scanned lag length both in the x- and y-directions was 3 mm for the planar surfaces and 0.5 mm for the concave and convex surfaces. The reflected light wave front from the sample surface in Fig. 1 was directed to a beam splitter. The CCD camera, without an object lens, was located in the focal point of the diffractive element. The 4×4 light spot matrix image in the specular direction was recorded for analysis into the memory of a PC.

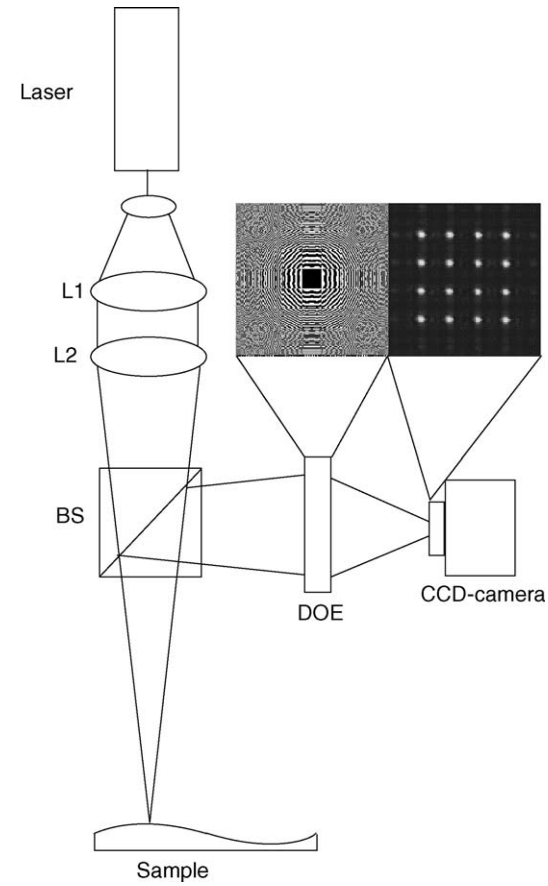

Fig. 1. Schematic diagram of DOG. L1 and L2, lenses; BS, beam splitter; DOE, diffractive optical element.

The innovations obtained with the present glossmeter are the following: (1) both the amplitude and phase information of scattered light are detected (because of the holographic nature of the light analyzing element), (2) the measurement is performed in normal incidence (conventional glossmeters are usually restricted to a relatively high angle of incidence because their resolution is poor between the small gloss variation of surfaces) and (3) non-destructive testing. The latter is beneficial since

Table 1
The codes of the samples and finishing processes

Shape material	Grinding	Wire EDM		Sink EDM		HSM		
	Planar	Planar	Planar	Concave	Convex	Planar	Concave	Convex
M0	E11	E12	E13	E14	E15	E16	E17	E18
M1	E21	E22	E23	E24	E25	E26	E27	E28
M2	E31	E32	E33	E34	E35	E36	E37	E38
M3	E41	E42	E43	E44	E45	E46	E47	E48
W4	E51	E52	E53	E54	E55	E56	E57	E58
W5	E61	E62	E63	E64	E65	E66	E67	E68
W6	E71	E72	E73	E74	E75	E76	E77	E78