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Feasibility of dimensional gauges made of plastic used for acceptance tests of coordinate measuring systems

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ABSTRACT

Dimensional X-ray computed tomography systems (DXCT) having the capability of measuring sizes and geometrical features are paid attention as a new type of coordinate measuring systems (CMS). A gauge used for verifying the measurement performance of DXCT is demanded for made of the material having low X-ray attenuation coefficient. In this study, the plastic is proposed to be used as a material of the gauge and the suitability of that is investigated. The observation of long-term dimensional stability shows Poly Phenylene Sulfide (PPS) is the most stable material in the observed plastics. The evaluation of actual CTE of plastic and of calibration uncertainty is demonstrated. The test uncertainty of the performance test of a coordinate measuring system including DXCT was estimated. The estimated uncertainty leads the guideline of conditions to be considered when the performance of DXCT is evaluated using the gauges.

1. Introduction

The measuring performance of X-ray computed tomography systems has been improving to be able to measure sizes and geometrical features of industrial parts accurately [1]. Such CT systems are called dimensional X-ray computed tomography systems (DXCT) and are widely drawing attention as a new type coordinate measuring systems (CMS) [2]. Verification of the dimensional measurement performance of the instruments according to industrial standards is indispensable to realize reliable quality control in manufacturing industry. The verification scheme for the DXCT is under discussion, which will be a new part of ISO 10360 series [3]. The principle of the verification stated in ISO 10360 consists of length measurements of calibrated gauges [4].

In order to observe practical measurement performance of DXCT, a gauge made of the same or a similar material as ordinary industrial parts is adequate. The most important characteristics of the material for this purpose is attenuation coefficient of X-ray.

DXCT equipped with a low energy X-ray source is unable to measure gauges made of conventional material such as steel or ceramics. It means that the material having relatively low X-ray attenuation coefficient e.g. plastics is demanded, although it is not common to use plastic material for calibrated gauges. The risk of using plastic is its long-term stability in geometry.

The suitability of plastics as the material of the gauges is investigated in this study. The experimental period of the study is determined for the initial 90 days, which is recognized to be valuable to capture the potentially significant secular change in dimension of the gauges made of plastic.

The observation of change in length of various plastics under different conditions indicates the feasibility of plastics as the material of the gauges.

2. Points to be considered in using the plastics as the material of the gauges

Three important points can be considered for the plastics, secular change in length, coefficient of thermal expansion (CTE), and possibility of calibration with small uncertainty.

Long-term stability of plastics in length is influenced mainly by two sources; the characteristics of water absorption and resistivity to X-ray irradiation. The long-term stability of plastics is observed in three different conditions considering above two sources;

- stored in a desiccator,
- stored in water, and
- stored in a desiccator and exposed by X-ray regularly.

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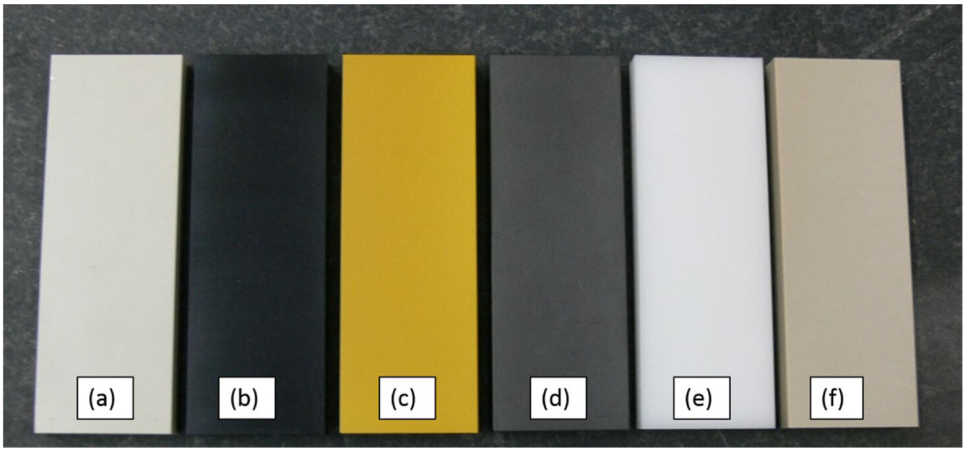

Fig. 1. Overview of plastic gauges. (a) PPS, (b) PBI, (c) Cepla, (d) Vespel, (e) POM, and (f) PEEK.

Table 1
Material property of plastics referred from catalog [5–10].

	density [g/cm^3]	CTE [ppm/K]	Young's modulus [GPa]
PPS	1.4	29	3.3
PBI	1.3	23	6.2
Cepla	1.4	36	2.6
Vespel	1.4	27	2.7
POM	1.4	110	2.2
PEEK	1.3	50	3.4

Typical plastics have larger CTE compared to that of metal and ceramics. It is often the case with the plastics that manufacturers report various CTE even if the name of the plastic is the same. In addition to that, the actual CTE of plastics is often considerably different from that reported by the manufacturer. Therefore, the actual CTE of plastics gauge is measured in this study.

The significant secular change, and large value and insufficient information of CTE give additional uncertainty contribution in the calibration of gauges made of plastics. The uncertainty of calibration is required to be sufficiently smaller than the performance of DXCT. By conducting thorough uncertainty estimation, the possibility to realize small enough uncertainty will be investigated. This investigation will lead to conditions to be considered when the gauges are calibrated and the performance of DXCT is evaluated using the gauges, which will be summarized as a guideline.

3. Experiment

3.1. Observation of the secular change

The length changes of the plastic gauges which are stored in various conditions are observed for three months in order to investigate the secular change.

3.1.1. Manufacturing of the plastic gauges

The gauge size is set to 100 mm by considering the measuring volume of the most of commercially available low energy X-ray CT. Three gauge blocks of 100 mm in the nominal length were made of six different plastic materials, in total 18 gauge blocks were produced. The plastics used are Poly Phenylene Sulfide (PPS), Poly Benz Imidazole (PBI), Polyimide-1 (product name Cepla), Polyimide-2 (product name Vespel), Poly Oxy Methylene (POM) and Poly Ether Ether Ketone (PEEK). See Fig. 1 for the overview. The material properties published by suppliers are summarized in Table 1.

3.1.2. Storage conditions

For each material, the three gauge blocks were stored in three different conditions:

a) stored in a desiccator as a normal storage condition for gauges used for length measurements,
b) submerged in water,
c) the same condition as a) and irradiated with X-ray periodically.

The X-ray irradiation is carried out between the measurements for 2 h with typical parameter settings when plastics are measured by DXCT; tube voltage of 160 kV, tube current of 160 mA and the distance between the source and the rotation axis (SRD) of 600 mm.

3.1.3. Measurement of the gauge blocks

The length of gauge blocks are compared with that of a reference gauge block (0 grade according to ISO 3650 [11]) which has the same nominal length and is made of ceramic. The comparisons are performed using a coordinate measuring machine (CMM) Crysta-Apex 776 manufactured by Mitutoyo Corporation. The measurement is scheduled every ten days.

3.1.4. Length measurement result

The secular change for each material for three months is shown in Fig 2. The markers drawn by circle, triangle, and cross indicate the length measurement results of the gauge blocks stored in the conditions a), b), and c) respectively.

Obviously PPS is the most and significantly stable material regardless of the storage conditions. The magnified view for PPS is shown in Fig. 3. The length changes do not exceed 6.0 mm under all three storage conditions a), b), and c), while the changes lies within the range of 2.0 mm under condition c). Cepla also shows stable behavior under the conditions a) and c), while it expands significantly by water absorption under the condition b). It is noted that all the plastic materials show length extension by water absorption, although the magnitudes are significantly different.

The PPS was selected as a primary candidate and used in the following experiments.

3.2. Determination of the actual CTE

The CTE of plastic materials ranges from 23 ppm/K up to 110 ppm/K which are significantly larger than that of a typical gauge material e.g. ceramic of 9.3 ppm/K. It is important to know the actual CTE accurately to perform the calibration of the gauge blocks with small uncertainty.

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