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Microcontact printing on metallic surfaces for optical deformation measurements

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Abstract. The measurement of the properties and behaviour of material is of fundamental importance in modern engineering. In recent years a breakthrough method for measuring surface deformation has been represented by digital image correlation. To determine local deformations in a material, an optical pattern is usually reproduced on the material surface. The reproduction of such patterns, especially at microscopic scale, is usually a slow and expensive procedure. A semi-automated device, able to print a suitable optical pattern on the metallic surface using micro-contact printing, was manufactured. Precision placing of the stamping head on the surface in order to avoid smearing of the pattern was reached. Specifically the stamp was placed with tolerances of some micrometres. Despite posing challenges in the handling of the ink and in the consistency of the patterns, this method proved viable for effective and fast creation of optical patterns.

Key words: microimprint, digital image correlation.

1. INTRODUCTION

Modern materials require the study of their behaviour under stress with high precision to locally determine the properties of the material [1]. There are several ways of measuring the deformation of a material, whereas the most used ones are strain gauges and interferometry. For a more detailed analysis of small-scale strains it is possible to attach an optical pattern on the surface (Fig. 1). When stress is applied, the pattern attached to the material surface will move according to the deformation of the specimen. A camera observing the surface is able to observe the movement of the pattern allowing the calculation of local stresses [2]. The pattern (Fig. 1) allows the camera to precisely estimate distances. Due to pixel dimensions the best accuracy of measurement is achieved when the size distribution of features is limited.

The largest features should not exceed twice the size of the smallest ones. Since phenomena at different length scales are observed, it is important to have a procedure that allows of several pattern choices. For optical measurements, the pattern should present clear edges and no smearing of features.

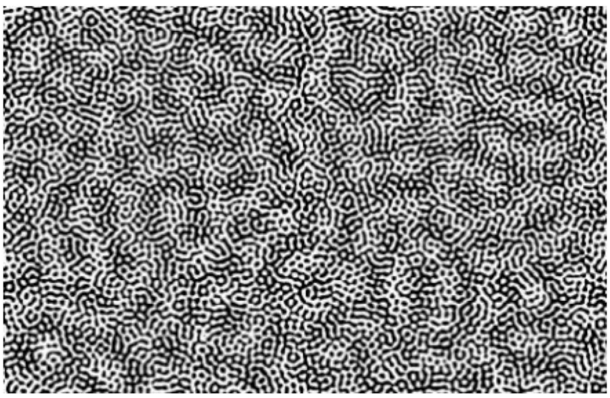

Fig. 1. A sample optical pattern. Actual feature dimension: 1–10 μm. The base of small features creates wave-like patterns at higher length scales [2].

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Among the many possible methods for optical pattern production, the easiest method is to create small droplets and to apply them to the desired surface. This can be achieved through the use of a simple nozzle, ultrasound excitements or electrically charging a capillary tube and accelerating droplets via an electric potential [3,4]. The problem lying in these methods is that the size distribution of droplets is not optimal. As a matter of fact, the droplets might merge together, forming a black spot. Where this happens, the displacement data result in an averaged value of a large surface. On the other hand, the areas left empty by ink will cause a local loss of information. Various lithography methods allow the creation of virtually any kind of pattern with any feature size down to hundreds of nanometres. Lithography methods can be used to print a desired pattern directly on the substrate but these processes have low productivity and a high cost [5,6].

The method adopted in this work is microcontact printing. Microcontact printing can roughly be divided into four steps. First the master stamp is made. Various methods can be used, but lithography provides a reliable method for the creation of high-quality master stamps with virtually any pattern (Fig. 2). A polydimethylsiloxane (PDMS) silicone rubber stamp is then created using the master stamp as a mould (Fig. 2). Ink is applied to the PDMS surface and dried. Finally, the inked PDMS and the specimen surface are put into contact, resulting in the ink transfer to the desired surface.

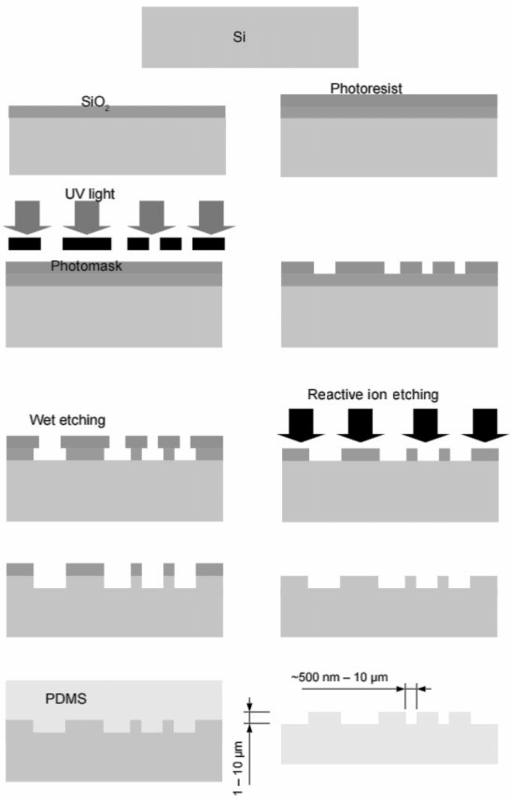

Fig. 2. Creation of Si and polydimethylsiloxane (PDMS) stamps. The silicon stamp is created with traditional photolithography methods. PDMS rubber is then poured on the master stamp, providing an exact negative of the silicon stamp.

Our research focused on microcontact printing as a part of optical measurements of strain deformation. The aim was to create a device capable of microcontact printing with adequate accuracy. For optical purposes a resolution from 0.5 to 10 µm is sufficient, being close to optical limits of cameras. Accuracy is achieved when the pattern has sharp features.

2. METHODS

2.1. Printing device

The printing device is built around a three-axis linear stage that has been automated through the use of three stepper motors, a microcontroller, a power source, and a stepper control module (Fig. 3). The stamp is located on a support anchored to a pneumatic piston (z_2-axis) attached to a vertical arm standing over the moving platform (Fig. 4). The parallelism between the stamp and the print surface is granted by an alignment mechanism located between the pneumatic piston and the vertical arm (Fig. 4). In detail the angle σ adjusts the angle around the x-axis and θ around the y-axis.

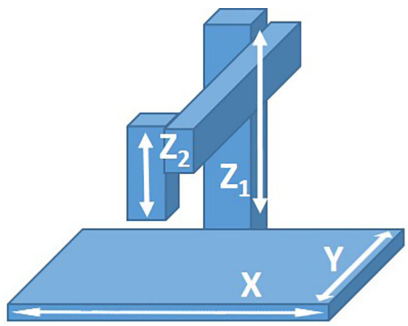

Fig. 3. Schematic representation of the printing device.

The printing force and speed of the stamp can be controlled through a control unit (Fig. 5). The force is regulated acting on a pressure relief valve that limits the maximum pressure in the system. The lower side of the piston is always under pressure, so that in case of the failure of the system, the stamp is lifted and the speed of the piston is adjusted with a flow valve acting on the inlet of the upper side of the piston. The stamping head is bolted at the end of the piston (Fig. 5).

The head supporting structure is attached to the main piston body via a linear bearing rail to increase accuracy.

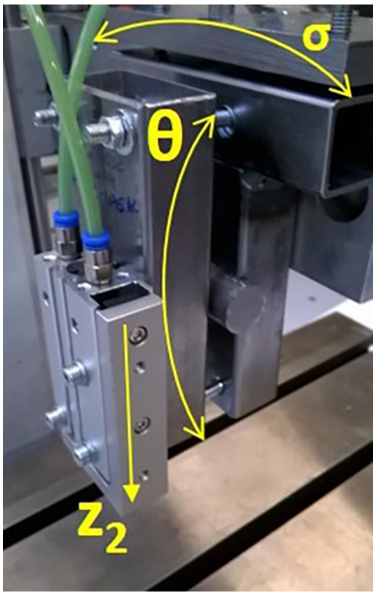

Fig. 4. Detail of the stamping arm.

The structure of the assembly leads to a containment of oscillations and to an accurate control of z velocity (from ca 0.1 mm to ca 50 mm per second) of the printing head (backlash between the base and the printing head less than 10 μm during the printing operation). The regulation system present over the stamping device allows of a 2-degree of freedom regulation in order to provide co-planarity between the specimen and the printing surface (Fig. 4). The parallelism between the printing surface and the surface to be printed was tested with a calibrated feeler of 0.05 mm, and this has been observed to be sufficient to get acceptable print (Fig. 6). The speed of the printing head was monitored as well, but it did not play a major role in the quality of the prints. Force on the other side has a two-sided behaviour. Too low force leads to an insufficient stamp deformation that does not guarantee complete adhesion between the two surfaces, thus resulting in unacceptable prints (Fig. 7). On the other hand, no upper limit has been observed for the force in order to guarantee sufficient printing quality.

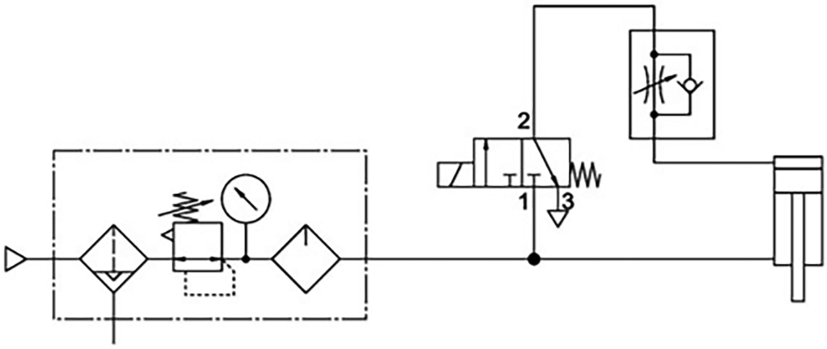

Fig. 5. Schematic representation of the pneumatic system.

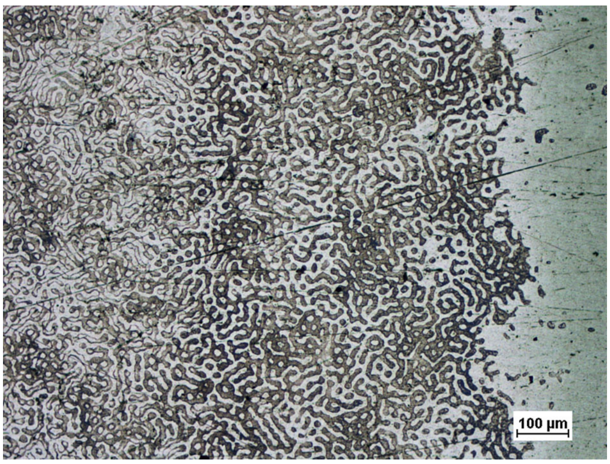

Fig. 6. The pattern successfully replicated on polished aluminium. The quality of this stamp is evaluated as acceptable.

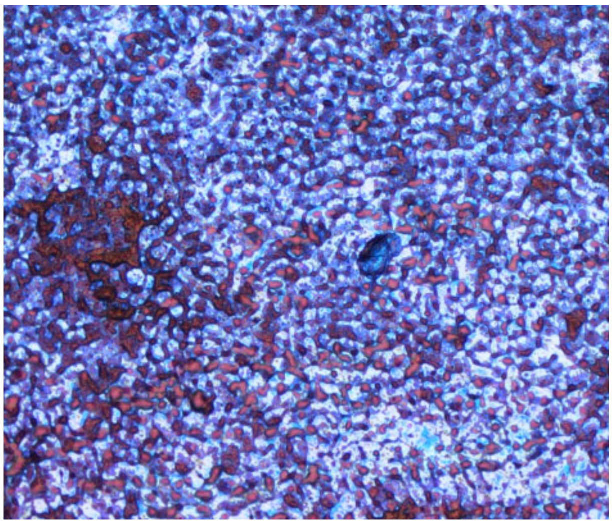

Fig. 7. Example of non-acceptable print, presenting excessive smear.

2.2. Stamp

The silicone rubber stamp used in the printing process is manufactured with the help of the master stamp. Several polymers can be used for replicating the stamps. PDMS rubber (*Sylgard* 184) has been chosen due to its ability to flow into sub-micrometric crevasses and trenches, thus providing a negative replica of the master stamp. The monomer is mixed with a curing agent and the resulting compound is poured on top of the master stamp. No bubbles or defects have been detected under a microscope on the stamp surface. Air bubbles develop inside PDMS during mixing of the curing agent and the bubbles are removed either with vacuum or by simply waiting. The stamp is then cured in an oven to decrease the curing time. Different temperatures of cooking lead to different consistency of PDMS. Once the PDMS has fully polymerized, it can be removed from the master stamp.

2.3. Measurement

For testing purposes several stamp patterns were used. The initial stamps presented straight lines 50, 20, and 10 μm in width in order to assess the printing quality with different feature sizes. Eventually we used a multiscale pattern [2]. After being applied to a rigid support, the stamp was inked, dried with air in order to let part of the solvent evaporate, and put into contact with the surface.

Prints were analysed under an optical microscope (Nikon Epiphot 200, Nikon E Plan 100x/0.90 and Nikon digital sight ds.u1). Printing quality was evaluated as positive if features from the stamp were present, their contrast was enough to be optically detected, and there was no smearing detectable with the optical microscope (Fig. 6). A print was evaluated successful if there was an area of at least 200 × 200 μm, where the pattern features were satisfying the quality level described above.

3. RESULTS

The device was able to print several acceptable stampings on a specimen. The required accuracy of positioning the stamp was reached (±100 μm, partial overlap of the stamps allowed). Unacceptable stampings resulted mainly from inconsistency in the application of ink to the PDMS surface (Fig. 7).

In the areas where the pattern was properly transferred, no smearing was present and defects in the print were small enough (2 orders of magnitude smaller than feature size) to be filtered out optically (Figs 6, 8). The print time of a typical print operation (inking, positioning, and stamping) was less than 2 min. The printing time for a specimen including preparation (device set up, ink set up, ca 10 stampings) was estimated to be under 1 h. The dots of the pattern will work as reference points during digital image correlation measures.

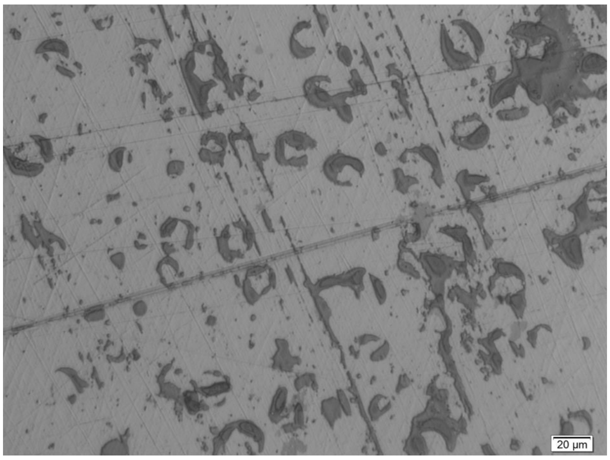

Fig. 8. Dots of ink on polished aluminium. The print presents sharp features. Long lines are due to scratches on the aluminium.

4. CONCLUSION

The printing device operated successfully in reproducing a micro-sized features pattern on metallic surfaces. The sharpness required for optical deformation measurement was achieved, revealing no defects detectable under an optical microscope. The smearing of the print with PDMS was revealed easier than expected, thanks to the elasticity of silicone.

The inking of the PDMS stamp was challenging, and the capability of creating a replicated pattern was limited to small areas. The automatized inking procedure would likely result in more consistent stamping than the actual manual one.

Pattern creation time has been reduced by an order of magnitude compared to traditional lithography methods. In order to fully substitute the traditional technology of printing at microscopic level, further refinement is required to improve process repeatability.

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Mikrokontaktprintimine metallpindadele deformatsioonide optiliseks mõõtmiseks

Federico Coren, Cesare Palestini, Mikko Lehto, Sven Bossuyt, Panu Kiviluoma, Aku Korhonen ja Petri Kuosmanen

Nüüdistootmises on materjali omaduste ja käitumise mõõtmine olulise tähtsusega. Viimastel aastatel on pinnadeformatsioonide mõõtmisel läbimurdeliseks meetodiks kujutise digitaalne korrelatsioon (DIC).

Kohtdeformatsioonide määramiseks materjalis kasutatakse tavaliselt materjali pinnale kantud optilist mustrit. Selliste mustrite reprodutseerimine, eriti mikroskoopilises mõõtkavas, on tavaliselt aeglane ja kulukas protseduur. On välja töötatud meetod ja poolautomaatne seade, millega on mikrokontaktprintimise meetodil võimalik metallpinnale printida sobiv optiline muster. Sellega saavutatakse templi pea täpne ja mustrite hägustumist vältiv paigutamine pinnale. Seejuures on templit võimalik paigutada mõnemikronilise tolerantsiga.

Vaatamata tindi kasutamisest ja mustrite tihedusest tingitud väljakutsetele, on tõestatud meetodi efektiivsus ning kiirus optiliste mustrite loomisel.