Study on selective laser sintering components with electrically conductive channels

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Abstract

Electrically conductive channels were created using conductive carbon cement (CCC) by a simple non-contact continuous deposition method on sintered DuraForm^{TM} Polyamide parts. The deposition system consisted of a drive circuit, a Micro Inert Solenoid Valve (MIV), a nozzle head and two liquid material reservoirs. Effect of CCC/solvent ratio, speed of deposition head and sintering condition of the Polyamide base material on the electrical properties of the conductive channels were investigated. The paper will then go on to discuss how these results relate to potential applications of Selective Laser Sintering (SLS) components with electrical property.

Keywords: SLS; electrically conductive channels; non-contact deposition

1. Introduction

SLS is a rapidly developing technology and its applications are no longer limited to conceptual testing but it is also used in building functional prototypes and even for rapid manufacturing [1,2]. Traditionally, commercial SLS only produces models with single materials or homogeneous mixtures. Previous work has demonstrated that it is possible to create SLS prototypes with different properties in desired positions. Ling and Gibson [3] tried to create colour RP components in which a secondary material, i.e. colour ink, was delivered. In view of this, if an electrically conductive material is chosen as the secondary material, it is possible to create SLS components with electrically conductive channels. In this study, Commercial Leit-CCC^{TM} (Conductive Carbon Cement) was chosen as the secondary material in creating the electrically conductive channels. A non-contact deposition method has been developed for delivering the CCC and it will be introduced in this paper.

Since SLS parts are porous, it is possible for CCC to infiltrate through the layers of a SLS component. One possible advantage of the phenomenon is that a conductive channel can be built through the layers. On the other hand, diffusion of CCC may adversely affect the electrical properties of the conductive channels within the layer. Previous study has shown that penetration of CCC into polyamide substrate at high temperature increased the resistance of CCC channels [4]. Apart from temperature, other parameters such as ink composition, feed rate of ink as well as porosity of the SLS component will all have an effect on the performance of the conductive channels. The objective of this study is to investigate the effects of ink concentration, deposition speed and the sintering condition of base material on the resistance of the CCC channels created on sintered DuraForm^{TM} Polyamide. Finally, some potential applications of SLS components with electrical property will also be discussed.

2. Experimental

2.1 Materials

Commercial Leit-CCC^{TM}(Conductive Carbon Cement) was used as the primary ingredient for formulating the electrically conductive ink used to create the electrically conductive channels. A typical composition of CCC consists of graphite, acrylic and organic solvents in which graphite is the conductive ingredient while acrylic serves as a binder. The organic solvents include acetone, methoxypropylacetate, xylene and butylacetate. Thinner was added to lower the viscosity of the conductive ink and extra amount of graphite powder was added to enhance the conductive nature of the ink. Four compositions of the ink were tested in this study and the details are shown in Table 1. The substrates, onto which the conductive channels were deposited, were sintered from DuraForm^{TM} Polyamide, Fig. 1, which has a melting point of 184°C [5].

Table 1 Compositions of the blended conductive ink

Type	CCC/graphite ratio	Paint*/thinner† ratio
I	½	1/3
II	½	1/5
III	½	1/7.5
IV	½	1/10

*Paint: mixture of commercial CCC and graphite powder
† thinner: mixture of organic solvents xylene, methoxypropylacetate, acetone and butylacetate in equal weight.

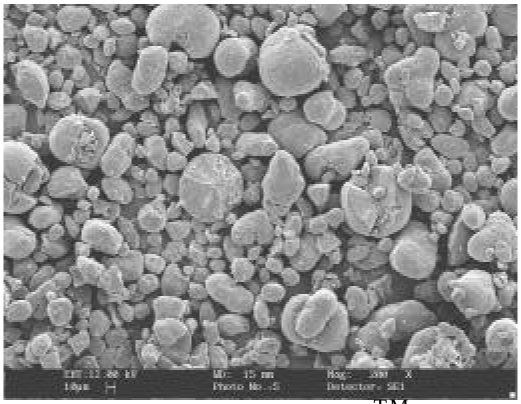


Figure 1 Powder of DuraForm^{TM} Polyamide

2.2 Sintering of DuraForm^{TM} Polyamide substrates

The sintering process was carried out using a DTM Sinterstation^{TM} 2000. The sintering condition can be varied by the fill laser power (P), beam speed (BS), scan spacing (SCSP) and the part bed temperature (T_b). When studying the effects of ink composition and deposition speed, DuraForm^{TM} Polyamide substrates were sintered at P = 8%, BS = 1257.3mms^{-1}, SCSP = 0.15mm and T_b = 167°C. The value of P was lower than the nominal setting but was still chosen as it could give acceptable physical properties for creating electrically conductive paths in SLS DuraForm^{TM} Polyamide samples. This setting gave a higher porosity than the normal setting but at the same time, the part was strong enough for handling. In studying the effect of sintering condition of DuraForm^{TM} Polyamide substrates on the performance of the CCC channels, the sintering process was carried out at P = 6% to 16% corresponding to ED = 0.01 J/mm^2 to 0.06 J/mm^2 according to the equation derived by Nelson [6].

2.3 Deposition of CCC

An experimental non-contact deposition system was developed for depositing the conductive ink (CCC) onto the polyamide substrates. It consists of a typical drive circuit, Fig.2, a Micro Inert Solenoid Valve (MIV), Fig.3, a nozzle head with diameter 0.328mm and two liquid material reservoirs. Fig.4 shows a schematic diagram of the set-up. The 3-way MIV was operated at 24Vdc.

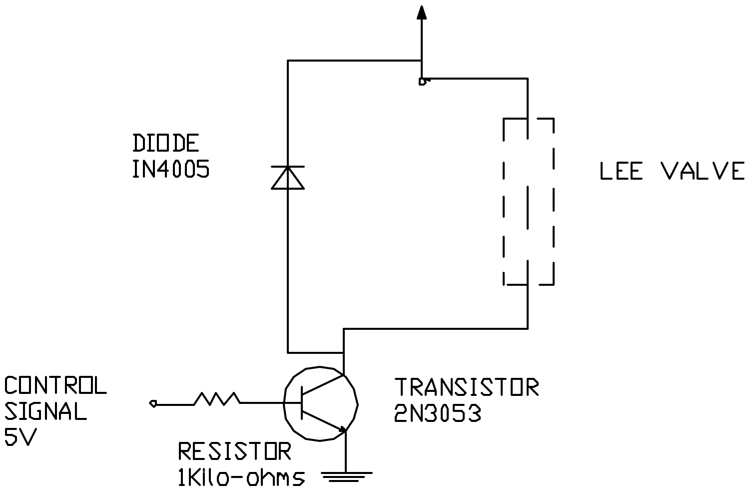


Fig. 2 Schematic Diagram of the typical drive circuit

Fig. 3 Micro Inert Solenoid (MIV)

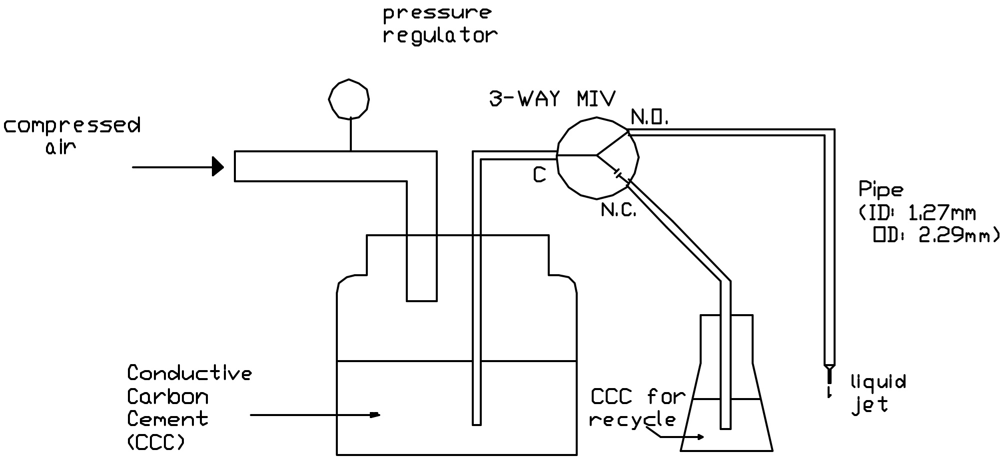


Fig. 4 Schematic Diagram of non-contact deposition system

Compressed air was first passed through a pressure regulator before entering the conductive ink reservoir. The air pressure in the ink reservoir was controlled at 10psi. The CCC was squeezed out through the outlet pipe (internal diameter = 1.27mm and external diameter = 2.29mm) and then through the 3-way MIV which was controlled by the typical drive circuit. Upon energising of the MIV solenoid, CCC was ejected from the nozzle head. When not energised, CCC was collected for recycling. The nozzle head was mounted on a computer controlled X-Y plotter.

For a constant feed rate from the nozzle, speed of movement of the deposition head will affect the amount of ink deposited per unit length. This would undoubtedly affect the electrical properties of the CCC channels created. To study the effect of deposition head speed, Type II ink was used. For the X-Y plotter, 100% speed setting equals to 1016mms^{-1}. Five deposition head speed settings (10%, 30%, 50%, 80% and 100%) were chosen for creating the CCC channels on the base material.

2.4 Resistance measurement of CCC channels

Resistance of the CCC channels created on the sintered DuraForm^{TM} Polyamide substrates were measured using a multimeter. The two electrodes were placed on the surface of the channels and the distance between the electrodes was 90mm. Five readings were taken for each measurement.

2.5 Scanning electron microscopy (SEM)

The SEM was conducted on a Cambridge Stereoscan 440 scanning electron microscope at operating voltages below 20kV. Specimens were dipped into liquid nitrogen before they were split to give the cross-sectional views. Samples were sputter coated with gold-palladium to avoid charging.

3 Results and Discussion

3.1 Performance of the non-contact deposition system

Non-contact deposition methods are more suitable to be employed during the SLS process because of the following reasons. In order to avoid curling, the chamber temperature within the DTM Sinterstation^{TM} 2000 is high, usually at the melting threshold of the polymer powder used [5]. The component inside the chamber is in a soft state and direct contact between the deposition head and the component will easily scratch or deform the component. Meanwhile, non-contact deposition methods can preserve the original surface morphology and the profile of the parts. The operation of a non-contact deposition system does not rely on the physical state of the material on which CCC is being deposited. No matter the base material is in solid state or molten state, non-contact deposition can still be applied.

Basically, there are two deposition modes for non-contact deposition, namely, continuous deposition and drop-on-demand [7]. With the present setup, preliminary experiments had demonstrated that continuous deposition gave a promising result for drawing conductive channels of simple geometry and it was therefore chosen in this study. However, there are some problems associated with the setup. The liquid jet emanating from the nozzle into an ambient gas is unstable [8]. The phenomenon is believed to be associated with a number of factors such as fluctuation of air pressure in the ink reservoir and the intrinsic property such as viscosity of the ink. Viscosity tends to reduce the jet breakup rate and increase the droplet size. Apart from these, sedimentation of graphite particles was also a problem but this could be solved by adding a magnetic stirrer in the ink reservoir.

3.2 Effect of deposition speed

Fig. 5 shows the CCC channels created on DuraForm^{TM} Polyamide substrates at different deposition speeds. When the deposition speed was low, CCC channels were wider as more material was delivered per unit length. The resistance of the CCC channels was found to increase almost linearly with the deposition speed, Fig.6. This is probably because of the reduction in the cross-sectional area of the channels deposited. There is always a trade off between the electrical performance and the geometric requirement of the CCC channels. Usually, the narrower the CCC channels, the higher is the resistance. Therefore, deposition speed can be one way of varying the electrical properties of a conductive channel within a part.

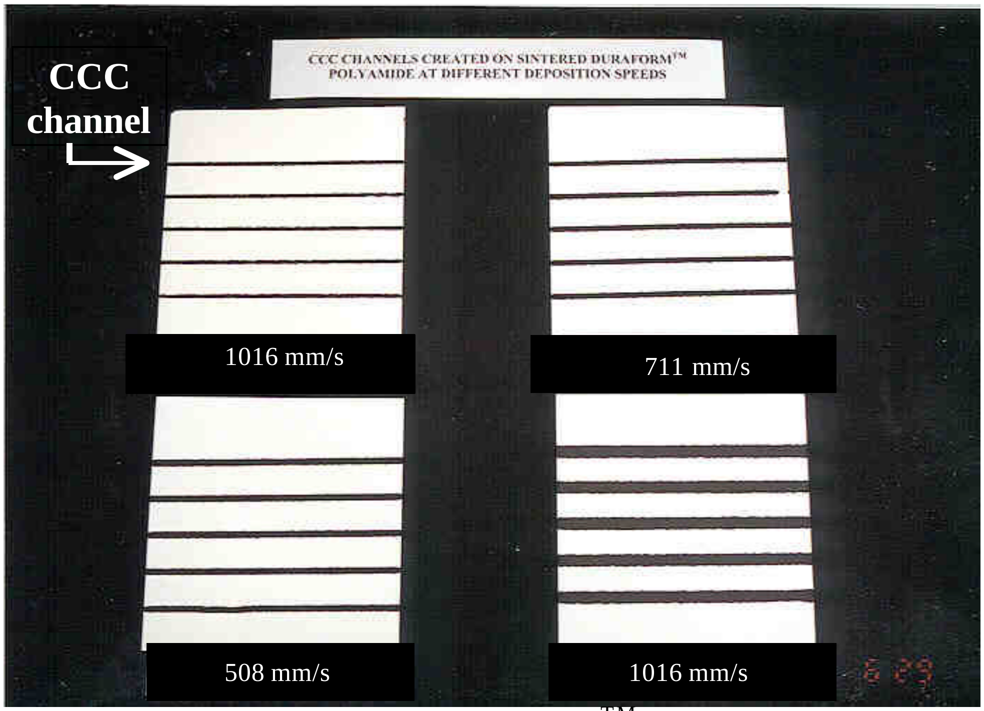


Fig. 5 Samples of CCC channels created on DuraForm^{TM} Polyamide sintered at 0.0212J/mm^2 using Type II conductive ink at different deposition speeds

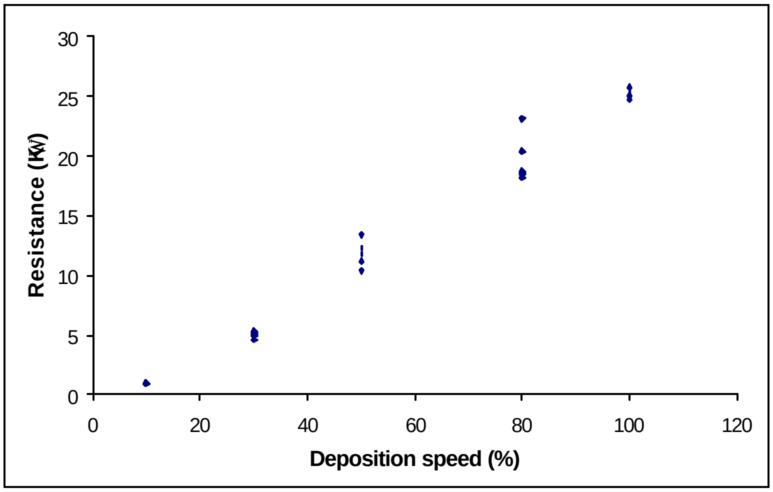


Fig. 6 Resistance of the CCC channels created at different deposition speeds

3.3 Effect of CCC/solvent ratio

Variation of resistance of the CCC channels created from Type I, II, III and IV conductive inks is shown in Fig. 7. The resistance increased when the paint/thinner ratio decreased. This can be attributed to the fact that when the paint/thinner ratio was low, there were less graphite particles in the conductive ink. This could also be seen by the lighter colour of CCC channels created from inks of low paint/thinner ratio. There was a significant increase in resistance when the paint to thinner ratio dropped from 1/7.5 to 1/10. This suggests that further reduction in the paint/thinner ratio would greatly affect the electrical conductive behaviour of the CCC channels.

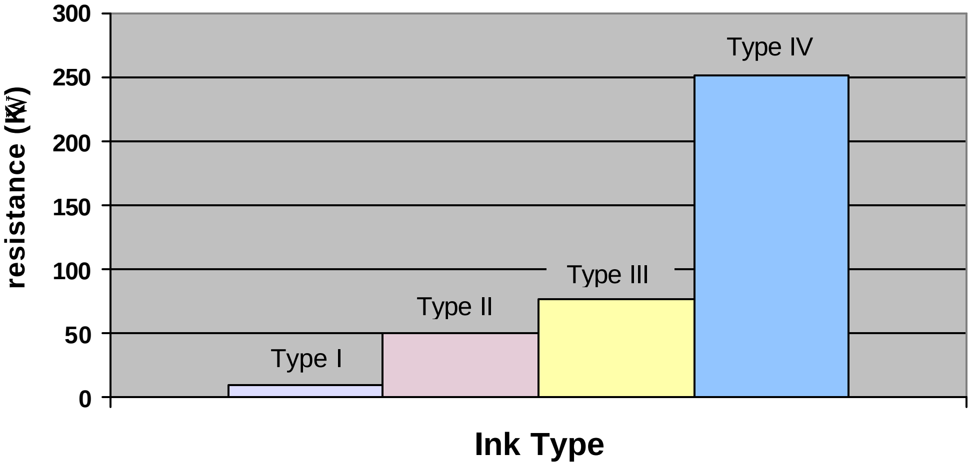
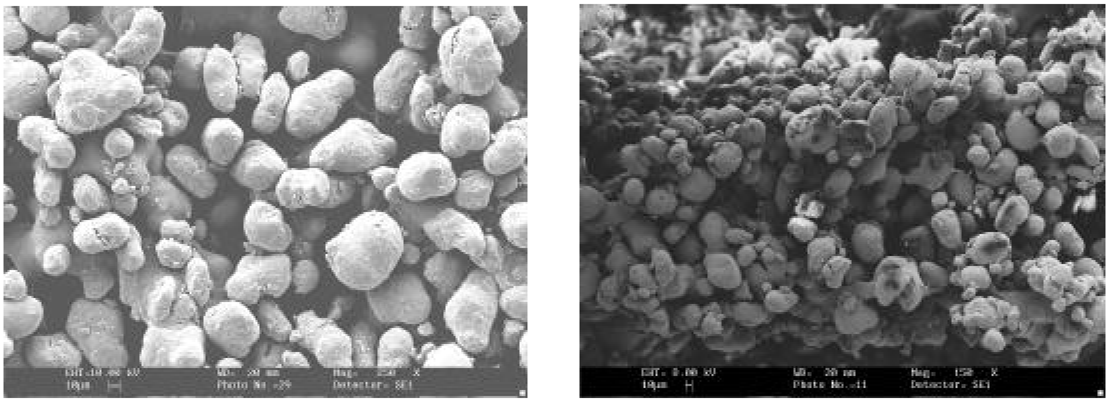


Fig. 7 Variation of the resistance of CCC channels created using different compositions of conductive ink on DuraForm^{TM} Polyamide substrate built under ED = 0.0212J/mm^2, ink deposition speed 1016ms^{-1}

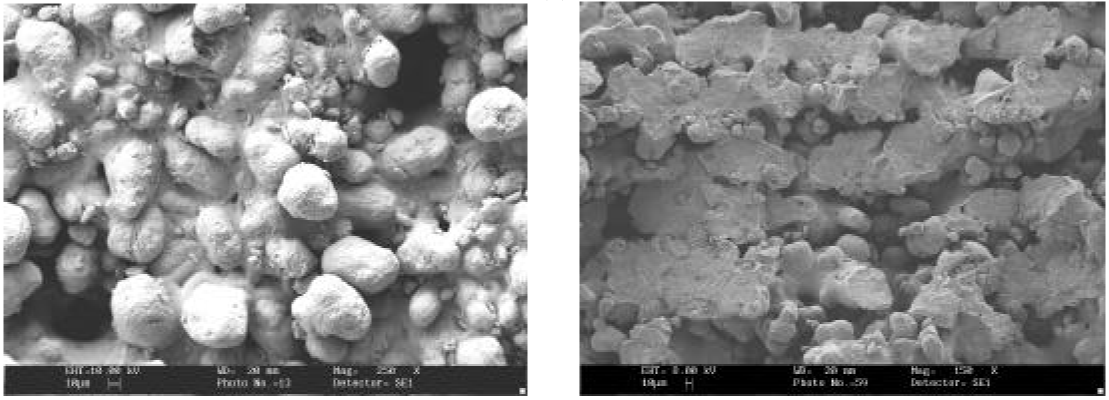
3.4 Effect of sintering condition of the base material

In building a SLS component with electrically conductive channels, ink composition and method of deposition of CCC are certainly not the only considerations. Since SLS parts built under different laser energy densities will have different physical densities, this effect was studied in relation to the process of creating SLS components with electrically conductive channels. Even though semi-crystalline materials like DuraForm^{TM} Polyamide have a limited range of usable energy density values in terms of tensile properties, such a range does exist. Also, parts may be fabricated using smaller energy densities in selected regions, providing suitable conditions for accommodating conductive materials. The variation in ED values and the effect on CCC channels was therefore studied.

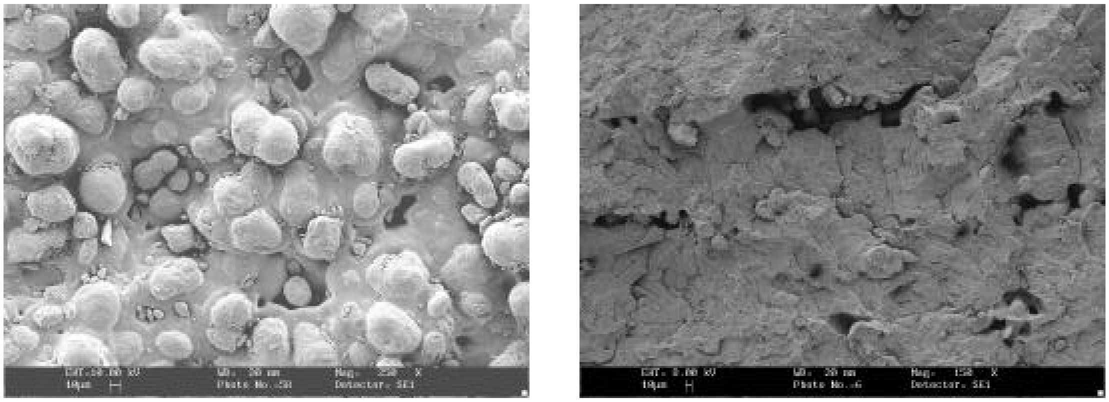
Fig. 8 shows the SEM micrographs of the surface and cross-sectional morphologies of DuraForm^{TM} Polyamide sintered at different ED. At ED = 0.0146J/mm^2, the polymer particles did not fuse well (Fig. 8a) and the surface morphology resembled that of unsintered DuraForm^{TM} Polyamide (Fig. 1), except some of the particles were slightly fused together. In this case, penetration of CCC through the layers was likely, Fig. 9. At a higher ED, better fusion of the powder was observed and the samples were less porous. A layered structure was observed in the cross-section of the sample built under ED = 0.0212J/mm^2 (Fig. 8b). Nevertheless, holes were still present through the layers and penetration of CCC might still be possible. However, it is difficult to distinguish individual layers from the sample processed at ED = 0.0371 J/mm^2 (Fig. 8c) and penetration of CCC is highly unlikely.



(a)



(b)



(c)

Fig. 8 Surface morphologies (left) and cross-sectional morphologies (right) of DuraForm^{TM} Polyamide sintered at different energy densities: a) 0.0146; b) 0.0212 and c) 0.0371 J/mm^2

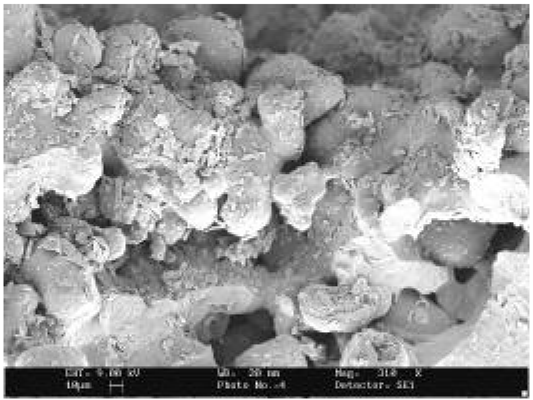


Fig. 9 Cross-section of DuraForm^{TM} Polyamdie substrate sintered at ED = 0.0212 J/mm^2, showing penetration of CCC

The variation of resistance of the CCC channels deposited on DuraForm^{TM} Polyamide sintered at different ED is shown in Fig. 10. There was a 29.4% drop in resistance when the ED increased from 0.016J/mm^2 to 0.053J/mm^2. This is related to the change of morphology of the substrates as described in the previous paragraph. At low ED, the porosity of the sintered component was high. Consequently, CCC would penetrate deeply into the substrate and this would adversely affect the performance of the conductive channels.

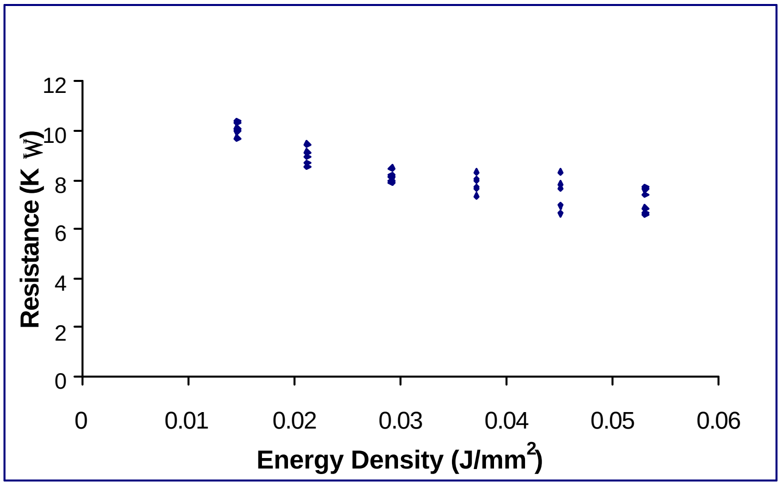


Fig.10 Variation of resistance of CCC channels created on DuraForm^{TM} Polyamide sintered at different energy densities, ink deposition speed 1016mms^{-1}, conductive ink used: Type I

3.5 Potential applications of SLS components with electrical property

EMI shielding

With an increasing use of plastic materials in electronic product design, conductive coatings for EMI shielding has become an important potential developing field. The increase in popularity of plastics is attributed to their non-conductive nature and the fact that they are transparent to electromagnetic waves. For digital electronic products manufactured using plastic enclosures, conductive coating becomes an important method of providing EMI shielding. With further development of the non-contact deposition system and a suitable choice of conductive ink, it is believed that plastic enclosure and conductive coating can be built at one time.

Heating elements and strain gauges

In this study, conductive ink is used in creating electrically conductive channels and these channels provide a passage for resistive components such as strain gauges. It is, however, believed that the application of this system can be expanded to a wider area. If the secondary materials being delivered possess different heat transfer coefficients, thermal properties of the SLS component can be altered as well. Heating elements can be built in any desired locations within the component by depositing materials with different heat transfer properties.

For such applications, CCC may not be the best material candidate. The main concern of this study is to examine the general trend of the effect of different parameters on the electrical performance of electrically conductive channels rather than the absolute values of the resistance measured. In this aspect, CCC has served the purpose. It may be necessary to deposit other materials with different electrical properties such as silver ink because of its good electrical conductivity. Further work is being carried out to improve the non-contact deposition system as well as to identifying a more suitable conductive ink.

4 Conclusion

The setup and operation of a simple non-contact deposition method was described. With further development of the system, it is possible to be employed during the SLS process. Effects of CCC/solvent ratio, deposition speed and morphology of the base material on the resistance of the conductive channels were evaluated. It was found that too a low CCC/solvent ratio would increase the resistance of the CCC channels. In addition, a lower resistance of the CCC channels could be achieved by either lowering the deposition speed or sintering the polymer substrate at a higher ED. Among the three factors that affect the performance of the CCC channels, CCC/solvent ratio was found to play a major role as it greatly affected the resistance of the CCC channels.

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