Surface Engineering Improvements and Opportunities with Electron Beams

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Recent developments at TWI in electron beam technology demonstrate how an electron beam used at lower power may be employed for a variety of purposes including a novel process, Surfi-Sculpt®. Surfi-Sculpt can neither be described as an additive nor machining process but rather as a process which relies on the interaction between the power beam and the workpiece to locally melt and move the parent material on the surface. This paper describes the mechanism of the Surfi-Sculpt process and discusses potential applications of the technology for heat exchangers and orthopaedic implants. The high level of reproducibility and material properties resulting from the process are addressed.

Подобрения и възможности на повърхностната обработка с електронен сноп (Томас Пинто, Анита Бъкстон, Кевин Ниайли, Стюарт Барнс). *Последните разработки в Института по заваряване в Обединеното кралство в областта на електроннолъчевите технологии демонстрират как електронен лъч с ниска мощност може да бъде използван за различни процеси, включително за патентования Surfi-Sculpt. Този процес е нито добавящ, нито фрезоващ процес, а е основан на взаимодействието между мощния сноп и образеца за локално стапяне и предвижване на стопения метал по повърхността. Тази работа описва механизма на Surfi-Sculpt процеса и обобщава някои потенциални приложения на технологията за топлообменници и ортопедични импланти. Обсъдени са високата възпроизводимост и свойствата на материала в резултат на процеса.*

Introduction

The Surfi-Sculpt process

When an electron beam interacts with a work piece, a capillary is generated. At the same time, a bulge of material is formed on the surface of the parent material [1].

Surfi-Sculpt® [2] is a novel process which manipulates this ‘bulge’ of the material. The electron beam interacts with the material surface to form a protrusion and a corresponding intrusion when the beam moves over the surface at low power, shown in Fig. 1. Surfi-Sculpt can be utilised to produce an area of features directly formed from the parent material. In order to be able to produce these features, a power beam, such as an electron beam, is deflected rapidly over a substrate surface to displace material in a controlled manner.

Surfi-Sculpt works by the following two means:

- When the electron beam is paused temporarily, rapid melting and evaporation of the parent material occurs giving rise to a partially penetrating capillary surrounded by solidified material;
- The manipulation of the electron beam, using a defined deflection pattern, causes material to be moved in the reverse direction. This harnesses the combined effects of temperature-variant surface tension and vapour pressure at the beam interaction site in order to create a protrusion and intrusion.

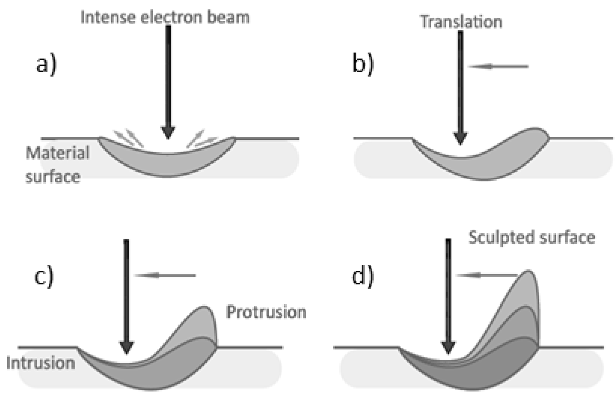

Fig.1. Schematic diagram of Surfi-Sculpt process (reproduced by permission TWI Ltd).

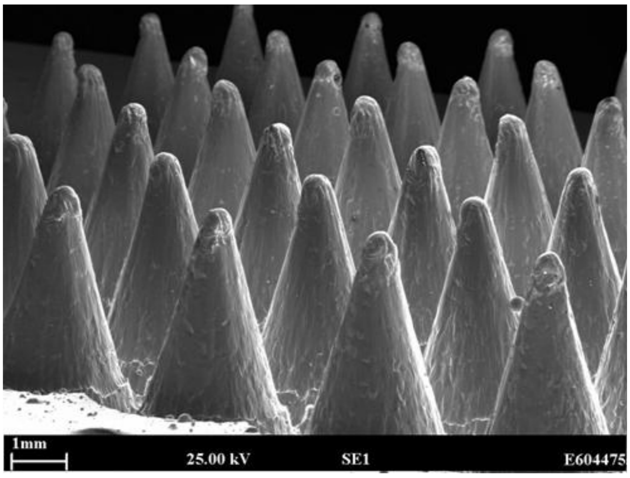

Fig.2. Example cones produced by Surfi-Sculpt on Ti6Al4V (reproduced by permission TWI Ltd).

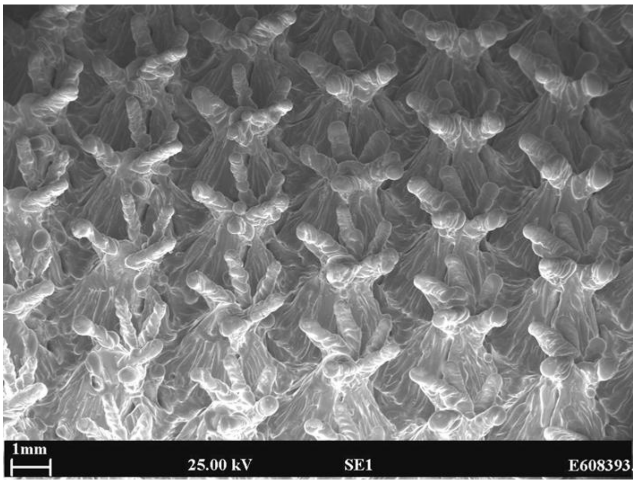

Fig.3. A complex surface produced by multi-stage Surfi-Sculpt on Ti6Al4V (reproduced by permission TWI Ltd).

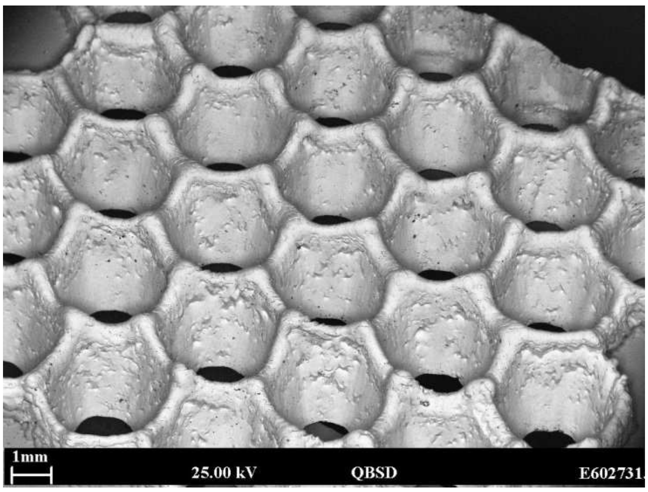

Fig.4. A honeycomb-like structure created by Surfi-Sculpt on Ti6Al4V (reproduced by permission TWI Ltd).

The success of Surfi-Sculpt is dependent on careful control of the above two means through manipulation of electron beam parameters including, but not limited to, beam accelerating potential, beam current and focus, to produce features of the desired aspect ratio [3].

As a result, an array of protrusions or features above the original surface and a corresponding array of intrusions or cavities create complex textured surfaces, examples of which are shown in Figs. 2, 3 and 4. High aspect ratio protrusions a few millimetres in height, ridges, channels, cones and burr-free holes can be produced using the process. When interacting with an electron beam, the ability of a material to form a stable liquid phase is critical to the success of the process. To date, the materials which can be successfully processed include metals, polymers, ceramics and glasses. The best results so far, in terms of the quality of feature produced, have been achieved in metals such as stainless steel, titanium and copper. Surfaces can be processed in a matter of seconds per square centimetre.

Surfaces tailored for specific applications can be created due to the capability to significantly vary the size, shape and distribution of the features.

The control system relies upon a pattern of deflection, an example of which is shown in Fig. 5.

Application areas

The Surfi-Sculpt process has shown particular potential in the areas of heat exchange and orthopaedic implants. Work in these areas is described below.

Heat exchange

Previous research by Buxton et al. [4] has shown that, at low Reynolds numbers, there is nearly 50% improvement in the heat transfer coefficient with Surfi-Sculpt surfaces compared to non-textured surfaces. This work is currently under further investigation through an EC funded project ‘HeatSculptor’. This is aiming to create Surfi-Sculpt surfaces based upon thermal modelling to incorporate significant design and performance improvements to heat exchangers which could not be achieved by other traditional manufacturing routes such as milling or etching.

Orthopaedic implants

Interest has been shown in the use of Surfi-Sculpt to enhance the performance of bone/implant interface. Work is currently planned to investigate the following key areas:

- Primary fixation of cementless implants – through the ‘bite’ due to the roughness of the

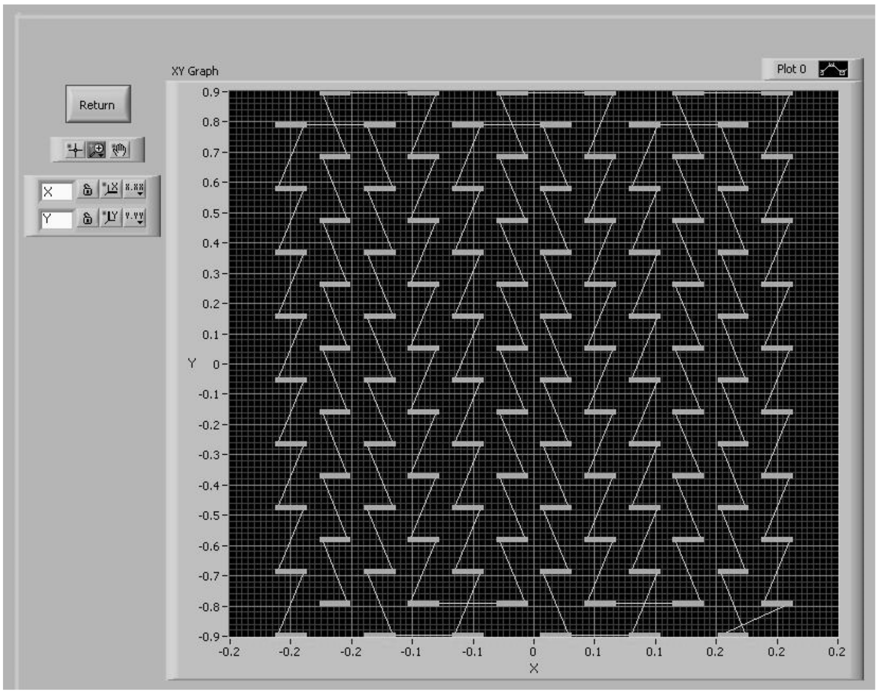

Fig.5. Screen shot of TWIs control software showing an example deflection pattern (reproduced by permission TWI Ltd).

surface;
- Minimising bone resorption – through load transfer over wider areas;
- Accelerating bony ingrowth from the porosity of the produced texture.

As with all applications, the strength and integrity of the features are critical, particularly the fatigue properties and the biological response to Surfi-Sculpt features.

Material properties

It is recognised that the Surfi-Sculpt process alters the microstructure of the parent material since it is thought that the microstructure of the protrusion is different to the parent metal due to the melting followed by very rapid cooling rate; however, this can be controlled through modification of the processing parameters [5].

Reproducibility

A study was conducted to assess the reproducibility of Surfi-Sculpt focusing on the following two elements:
- Spacing between consecutive Surfi-Sculpt features;
- Difference in volume of material in a protrusion compared to the volume of material displaced in the corresponding intrusion.

As part of the work, micro computed tomography (µCT) analysis was completed on a small section of the Surfi-Sculpt sample shown in Fig. 6. Using approximated surface determination, the analysis indicated that the volume of material in the protrusion is similar to the volume of material removed from the intrusion as shown in Fig. 7. Further investigation is required to confirm the cause of the small difference in volume.

The deflection pattern was created with spacing of 4mm between each feature with the layout shown in Fig. 8 [6]. Measurements were taken using a shadowgraph of the feature spacing. The results presented in Fig. 9 show that there is no statistically significant variation (95% confidence limits) in the spacing between features within the rows.

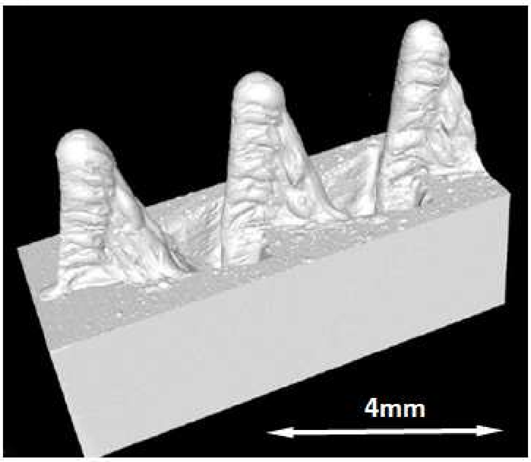

Fig. 6. µCT scan of Surfi-Sculpt sample (reproduced by permission TWI Ltd).

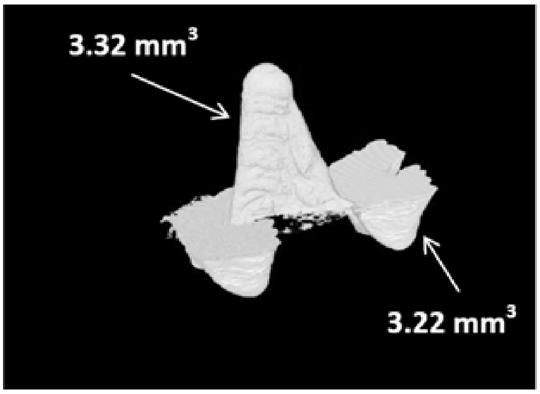

Fig. 7. Volume of a Surfi-Sculpt feature and intrusion (reproduced by permission TWI Ltd).

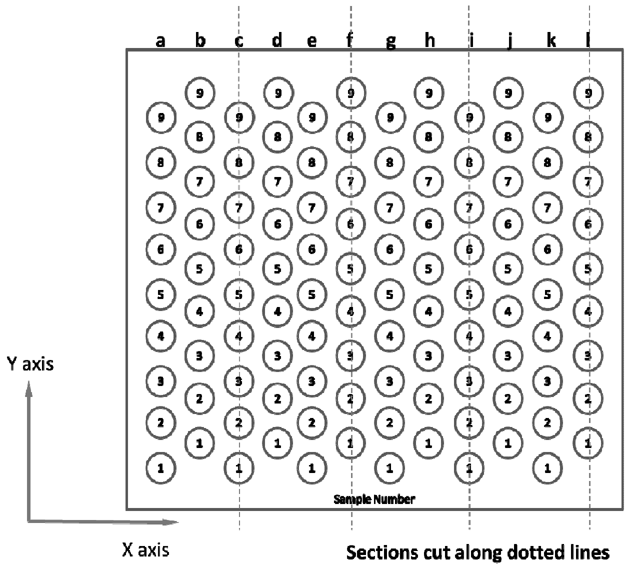

Fig. 8. Schematic diagram of Surfi-Sculpt feature locations highlighting how the sample was sectioned (reproduced by permission TWI Ltd).

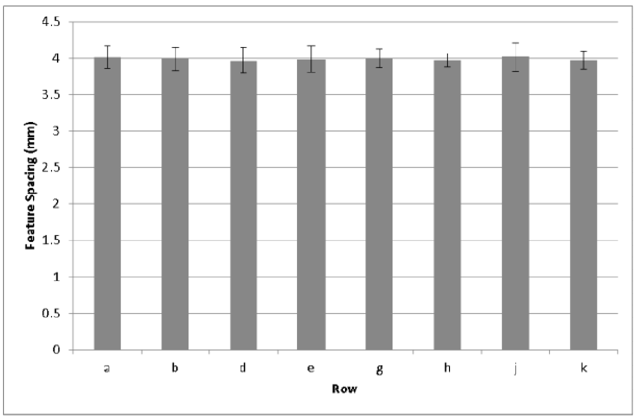

Fig. 9. Graph of average feature spacing on Surfi-Sculpt sample (reproduced by permission TWI Ltd).

Summary

It has been shown that the Surfi-Sculpt process has potential for two particular applications discussed in this paper. A selection of the wide range of possible surfaces has been presented.

The Surfi-Sculpt process offers:

- Complex functional surfaces which can be customised;
- Features and intrusions from 10μm to a few mm in height or depth;
- Rapid and flexible processing (cm^2/sec);
- Applicability to a wide range of materials;
- High degree of reproducibility;
- Low overall heat input.

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