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Reviewed Paper

Implementation of tophat profile laser into low temperature process of Poly Phenylene Sulfide

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Abstract

Poly Phenylene Sulfide is a high performance plastics that is used in high-value parts. The most commercially available plastic laser sintering machines employ Gaussian profile CO_2 laser. In this research, low temperature process of the material with tophat profile laser is tested. By using tophat profile, a tensile strength of 64.5 MPa was obtained. The value is equivalent to 75% of those from injection molding and 140% of standard laser sintered polyamide. Tophat profile effectively suppressed sparkling and fuming and improved surface finish decreasing surplus sintering or sticking powder

Introduction

In recent years, application of plastic laser sintering (LS) to end-parts production is expanding in aerospace and medical industries. Although these applications often require high performance plastics possessing high strength, high heat resistance and/or biological compatibility, process of these plastics has not been commercialized, or is extremely expensive. This limitation in material performance restricts application range of LS.

One of the problems with LS process is part warpage caused by layer-by-layer shrinkage. To avoid this, in commercially available systems, powder bed is preheated so as to keep its temperature in a range known as “process window,” which is between recrystallization and melting temperature [1]. Although this powder preheating effectively prevents warpage, it causes another problem. Generally, plastic does not melt or recrystallize at a certain point of temperature but in a range. When the ranges are close to each other, the temperature control is quite difficult, or the window even closes. Additionally, preheating requires LS machine with a high-heat-resistance when we use high performance plastics due to their high melting temperature. Poly Ether Ether Ketone (PEEK) is one of the high performance plastics that has the highest performances. In process of PEEK, powder bed temperature must be kept above 300°C [2] and this preheating elevates the machine price and deteriorates the powder recyclability.

Previously, the authors introduced and tested a novel LS process which prevents part warpage by fixing a part to a rigid base plate instead of preheating powder bed at such a high temperature [3, 4]. In the following, we call this novel process and standard one as “low temperature process” and “high temperature process.” Additionally, the authors implemented this technology for processing of PEEK, and succeeded in prototyping several parts at a low bed temperature of 200°C

[5].
Poly Phenylene Sulfide (PPS) is also a high performance plastics. Though PPS is slightly inferior to PEEK in terms of physical performance, its price is much cheaper than PEEK. As a result, there are many products made of PPS [6], and this shows great demand for PPS as a material of high-value functional parts. Technically speaking, we can expect that LS process of PPS is easier than PEEK because of its lower melting temperature.

In this research, low temperature process of PPS is tested. Sparkling and fuming, which is also found in process of PEEK, is suppressed by reducing peak intensity of light. For this purpose tophat profile laser is employed. Quality of obtained parts in terms of mechanical strength and precision is discussed. Although tophat profile laser is utilized in selective laser melting of metal powder [7], no plastic LS machine using this laser is commercialized yet. Advantage of using tophat profile laser in plastic LS is also discussed.

Material and Method

Material

PPS powder having median diameter of 75μm was employed. Median diameter was measured with a particle size analyzer (MT3300, MicrotrackBEL Corp.). Thermal and mechanical performance of an injection molded part of non-reinforced PPS was summarized in Tbl.1 [8]. Optical micrograph of PPS powder grains is shown in Fig.1

Tbl.1 Performance of material (typical example of PPS)

Type of material	PPS(Poly Phenylene Sulfide)
True density	1.35 g/cm^3
Melting point	275 °C
Tensile strength	85 MPa

Fig.1 Optical micrograph of PPS powder grains

Laser sintering apparatus and tophat profile laser

Two experimental apparatuses are employed. CO_2 lasers are installed to both machines. One is equipped with Gaussian profile (or single mode) optics, and the other with tophat profile. The beam spot diameter of Gaussian profile is adjustable from 130μm to 340μm by changing the distance between focusing lens and powder bed. The beam spot diameter of the tophat profile is 480μm. To compare the influence of profiles under the same laser power, beam spot diameter of Gaussian profile laser is adjusted to 228μm so that the two profile share the same intensity gradient at the beam edge as shown in Fig.4. A pair of galvanometers is able to scan the beam in *x* and *y* direction in a range of approximately 100×100mm. To inhibit oxidation of fabricated parts, oxygen concentration of building chamber is lowered below 0.1% by nitrogen gas purge. It was unable to make parts of PPS with high temperature process because of the highest powder bed temperature of these apparatuses is 200°C. An injection molded PPS plate is used as the base plate.

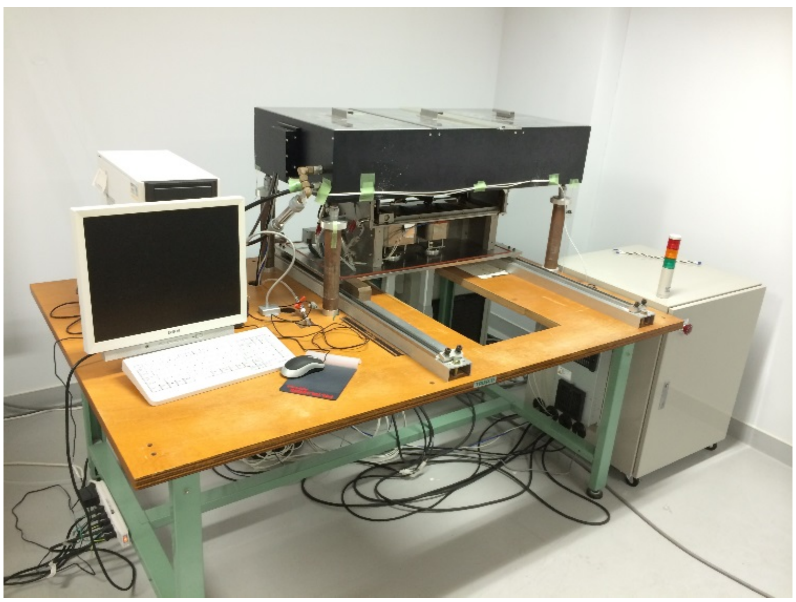

Fig.2 Laser sintering system

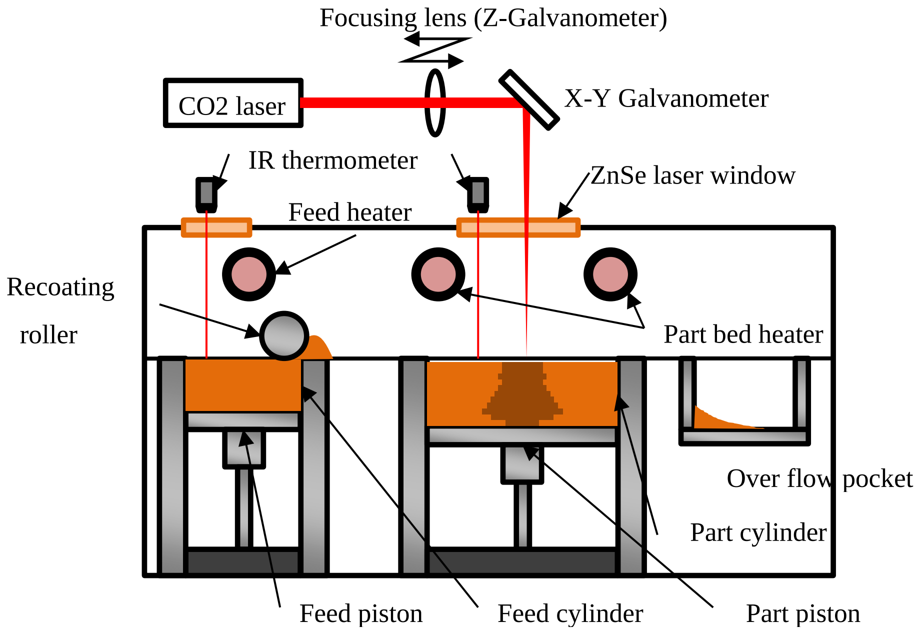

Fig.3 Schematic view of the laser sintering system

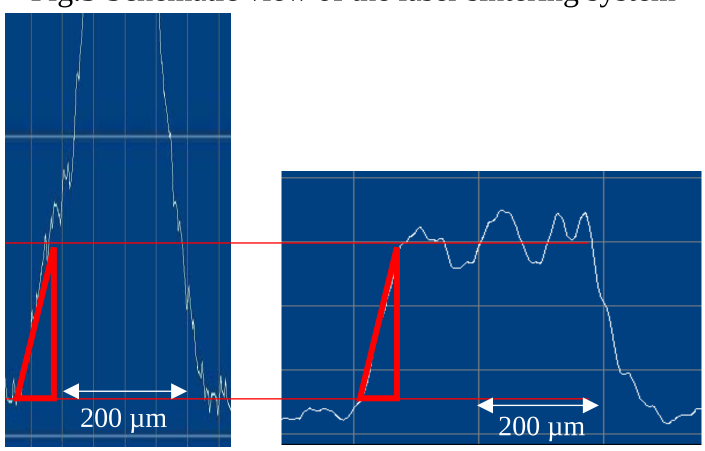

Fig.4 Profiles of Gaussian and tophat profile laser

Visual observation and measurement

To evaluate quality of fabricated parts, density and tensile strength were measured. Density is used as an index of strength. Fracture surface of parts were visually observed to help understanding of sintering mechanism. Sparkling and fuming during process are the main obstacle of process. To suppress them, surface of the bed was visually observed to know the cause of these phenomena. To evaluate process precision, side surface of parts is visually observed.

These observation of fracture and side surface for evaluations was carried out with SEM (VHX-2000 and VHX-D510, KEYENCE). Tensile test pieces were fabricated and measure with universal testing machine (Series 5560, INSTRON). Size of test pieces was shown in Fig.5 and conformed to ISO 527-2. Tensile speed was 2mm/min. Density measurement was carried out by Archimedes principle using electronic balance (AX120, SHIMADZU Corp.) for weight measurements.

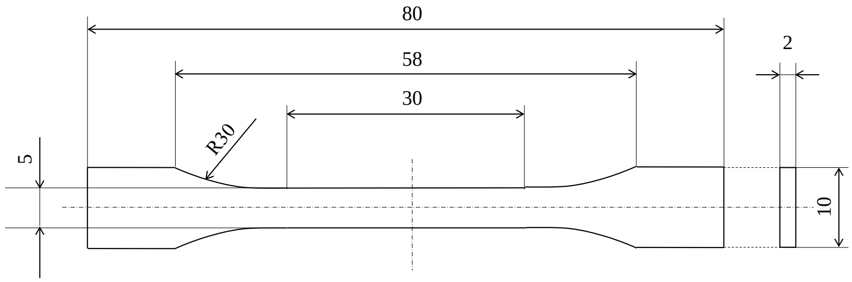

Fig.5 Size of tensile test piece

Build parameter of each laser

Powder bed temperature was maintained 200°C and layer thickness was set to 100μm in process. Build parameters of Gaussian and tophat beam were shown in Tbl.2. Scanning speed and interval were adjusted so that the two profiles give the same energy per unit area.

Tbl.2 Build parameter for the Gaussian and tophat beam

Profile	Laser power	Scanning speed	Scanning interval	Energy per unit area	Beam diameter
Gaussian	11 W	0.92 m/s	100 μm	119 kJ/m^2	228 μm
Tophat	11 W	1.0 m/s	90 μm	122 kJ/m^2	480 μm

<u>Experimental Results</u>

Fabrication process and density with Gaussian profile laser

Fig.6 shows powder bed in fabrication process of PPS with Gaussian profile laser. Fig.7 shows sparkling and fuming in fabrication process of PEEK[5]. In fig.6, fuming was not observed, however sparkling was observed which was not extremely big. Relative density was obtained 92.6% (1.25g/cm^3).

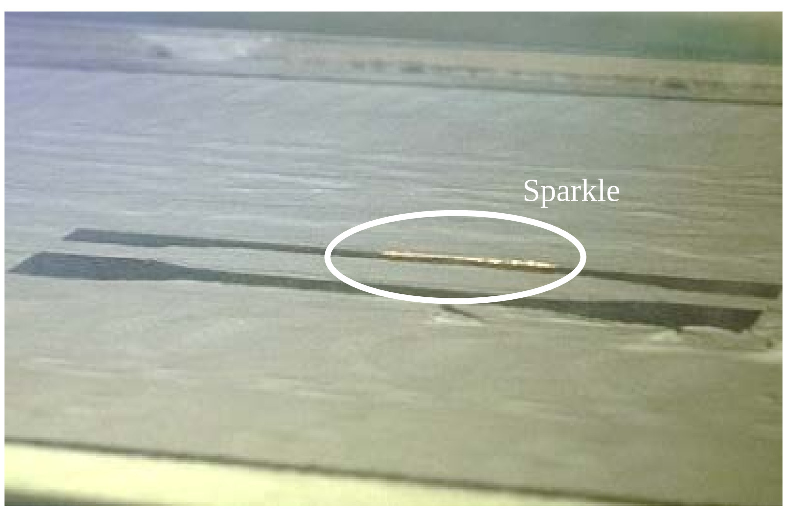

Fig.6 Sparkle in process with Gaussian profile laser

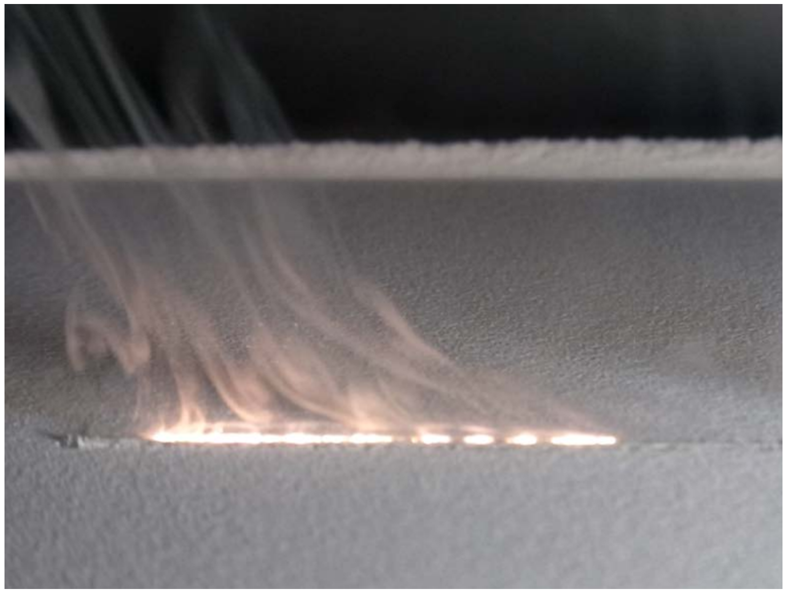

Fig.7 Sparkling and fuming in process of PEEK[5]

Fabrication process and density with tophat profile laser

Fig.8 shows powder bed in fabrication process of PPS with tophat profile laser. Fuming was not observed either. Sparkling was suppressed successfully in comparison with Gaussian profile laser. Small sparks were observed yet, but it is not as much as it can obstacle the process or lower the part quality. Relative density was improved to 95.6% (1.29g/cm^3.)

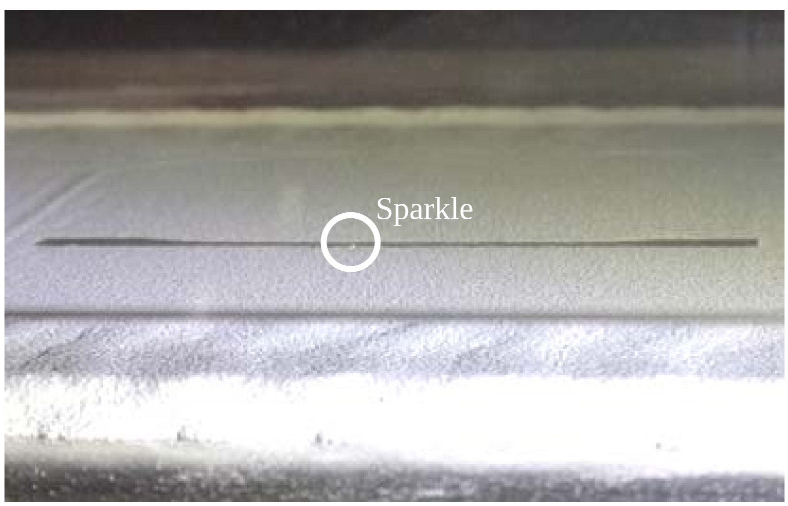

Fig.8 Sparkle in process with tophat profile laser

Tensile strength

Results of tensile strength measurement were summarized Tbl.3 and Fig.9. Tensile strength tests were carried out three time per each profile laser. Average tensile strength of test pieces fabricated with Gaussian and tophat beam were 47.2MPa and 64.5MPa, respectively. Using tophat profile improved tensile strength by a factor of 1.37, although almost the same amount of energy was supplied per unit area.

Tbl.3 Tensile strength of parts fabricated

Profile	Energy per unit area	Tensile strength
Gaussian	119 kJ/m^2	47.2 MPa
Tophat	122 kJ/m^2	64.5 MPa

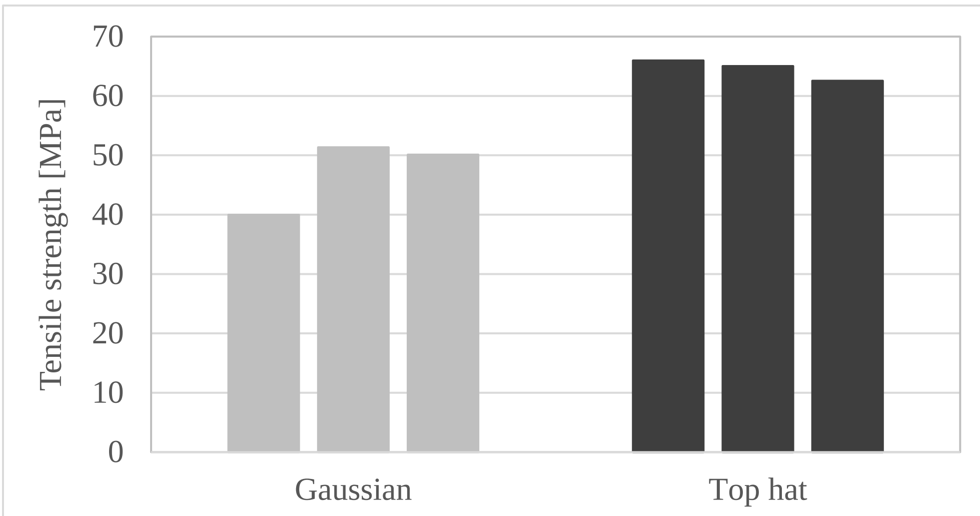

Fig.9 Results of tensile strength test

Fracture surface and side surface

SEM images of fracture surfaces are shown in Fig.10, 11. On the fracture surface of parts obtained by Gaussian profile, many linear horizontal cracks are observed. The cracks occur at an interval of 100 or 200μm. Although we can see cracks on the fracture surface of parts from tophat profile, they are much shorter, not horizontal and nonperiodic. SEM images of exterior side surfaces of parts are shown in Fig.12, 13. The part obtained by tophat profile is smoother on the side surface. Amount of powder grains sticking on the surface looks smaller when tophat is used.

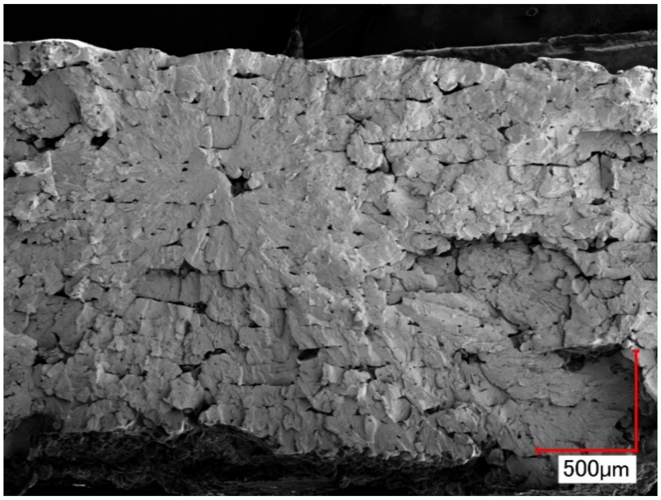

Fig.10 Fracture surface of the part obtained with Gaussian profile laser

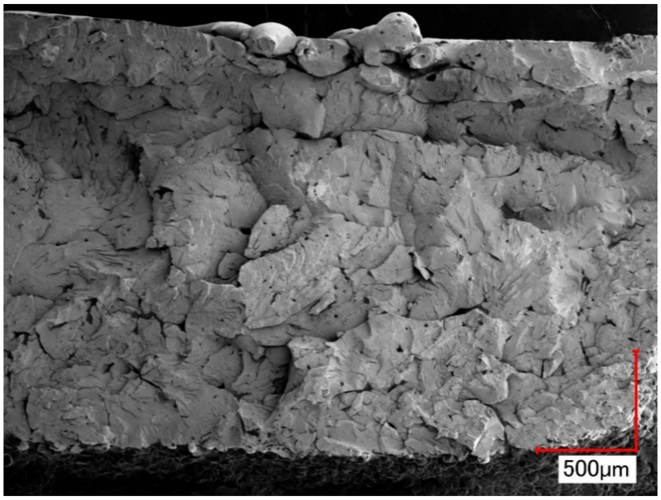

Fig.11Fracture surface of the part obtained with tophat profile laser

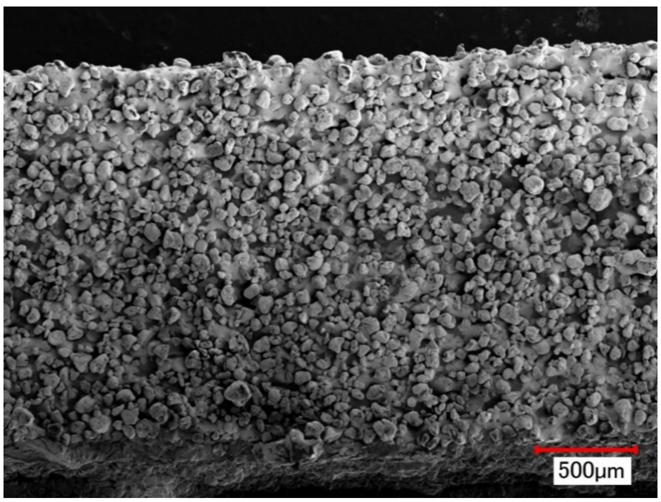

Fig.12 Side surface of the part obtained with Gaussian profile laser

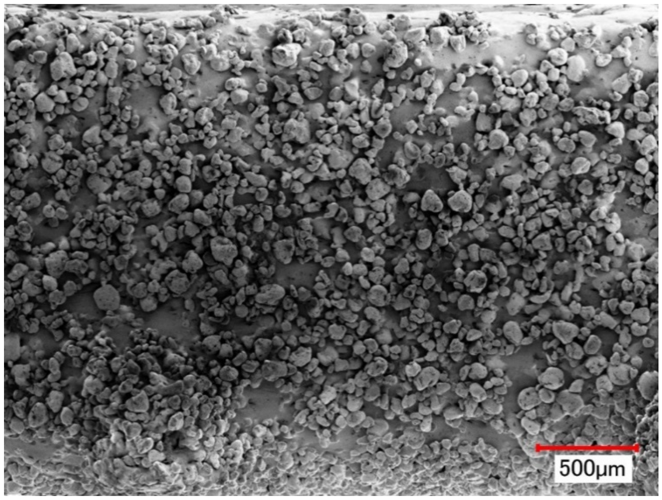

Fig.13Side surface of the part obtained with tophat profile laser

Discussion

In previous research, sparkling and fuming during processing PEEK were suppressed by expanding beam diameter to reduce intensity of light without decreasing laser power. In this research, it was found that tophat profile can suppressed the phenomena better. The reason for this improvement is that tophat profile reduces the peak intensity and supplies constant energy over its beam spot while Gaussian profile is strong in the middle and weak at the outer edge. Tophat profile makes improvement in terms of mechanical strength as well. Although the supplied energy per unit area is the same, tensile strength obtained by tophat profile is 1.4 times of what Gaussian beam can provide.

Tensile strength of parts obtained by tophat profile in this research was 64.5MPa. This is equivalent to 75% of injection molded parts and 140% of standard laser sintered polyamide (PA) [4, 5]. Considering that PPS has a better anti-heat performance than PA12 or 11, we can conclude that low temperature process of PPS can make dramatic progress in plastic laser sintering.

By the both of Gaussian and tophat profile laser, a high relative density more than 92% was obtained. The parts obtained by Gaussian profile includes long, horizontal and periodic cracks. The periodicity of the cracks and their interval, which is equivalent to layer thickness of 100μm or its integer multiple, shows that these cracks derive from boundary of layers. In contrast, parts obtained by tophat profile does not include trace of layers. This indicates tophat profile can provide better interlayer connection. It is surmised that light of tophat profile laser or heat generated by the laser penetrates into deeper place without causing other phenomena like sparkling.

Between tophat and Gaussian profile, we found differences in roughness and an amount of sticking powder of the exterior surface. Cause of these differences is not clear. Through investigation into definition or precision should be done in the near future.

Conclusion

PPS powder was successfully processed with low temperature process. It was confirmed that using tophat beam is effective to implement the process and obtain parts having high tensile strength by suppressing violent phenomena such as sparkling and fuming. Gaussian and tophat profile laser provide the same density when amount of energy per unit area is the same. However, tensile strength of parts obtained by tophat profile laser was 1.4 times as great as by Gaussian beam.

Tophat profile is effective to suppress sparkling and fuming. The profile also provide the parts with smooth exterior surface decreasing surplus sintering or sticking powder. Furthermore, tensile strength and morphology of internal structure were improved by using tophat profile laser.

ACKNOWLEDGEMENTS

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