論文 / 著書情報
Article / Book Information

題目(和文)	レーザ粉末焼結積層造形におけるPBT造形品の特性に関する研究
Title(English)	Study on material properties of poly(butylene terephthalate) processed by laser sintering
著者(和文)	荒井聡
Author(English)	Satoshi Arai
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第11279号, 授与年月日:2019年9月20日, 学位の種別:課程博士, 審査員:扇澤 敏明,鞠谷 雄士,森川 淳子,塩谷 正俊,淺井 茂雄
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第11279号, Conferred date:2019/9/20, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	材料 系 材料 コース	申請学位（専攻分野）： Academic Degree Requested	博士 （工学） Doctor of
学生氏名： Student's Name	荒井 聡	指導教員（主）： Academic Supervisor(main)	扇澤 敏明
		指導教員（副）： Academic Supervisor(sub)	

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words）

In recent years, additive manufacturing (AM) technology has been gaining attention due to popularization of low-cost 3D printers and improved performance and reduced cost of industrial equipment. Among AM technologies, selective laser sintering (SLS) is starting to be used not only for prototypes but also for production of final parts. However, the type of resin used for SLS is mainly polyamide, and its material limitation is the biggest problem. Although poly(butylene terephthalate) (PBT) features high heat resistance, good mechanical and electrical properties, high chemical resistance, and low cost, it is not commercially available as a resin for SLS, and very few studies have been done. Under those circumstances, in this study, the SLS process using PBT was investigated, and its various basic characteristics were evaluated and compared to those of an injection mold (IM) specimen.

As explained in Chapter 2, the influence of pulverization by cryogenic grinding was investigated by using copolymer PBT (cPBT) pellets with low crystallinity. The investigation revealed that in the case of powder made from cPBT pellets pulverized at low temperature, although melting point, crystalline form, and molecular weight are unchanged by cryomilling, contaminants produced during the pulverization acted as nucleating agents of cPBT, which increase the crystallization temperature of the pulverized powder. As a result, although the process window became smaller, it was demonstrated that setting the powder-bed temperature of the SLS process to 190 °C made it possible to produce shaped articles with excellent characteristics.

As explained in Chapter 3, flame retardancy (FR) of cPBT was investigated. As for powder, two kinds of powders were used: (i) pulverized powder of flame-retardant cPBT pellets obtained by adding 10 wt% of flame-retardant poly(pentabromobenzyl) acrylate (PPBBA) and 5 wt% of flame-retardant promoter antimony trioxide (ATO) to cPBT pellets (where ATO is embeded in PPBBA) and (ii) flame-retardant mixed powder obtained by dry-blending 10 wt% of PPBBA and 5 wt% of ATO pulverized into pulverized cPBT. It was revealed by the investigation that the combustion characteristics of the powder differ according to whether or not the ATO embeds in the PPBBA. Moreover, SLS specimens coated with ATO in cPBT and PPBBA showed superior mechanical and thermal properties than SLS specimens embedded in PPBBA with ATO. It was also revealed that although the combustion characteristics differed from specimens formed with either of the two powders, V0 grade in the UL 94 test could be attained with a thickness of 2 mm.

As reported in Chapter 2 and 3, the result of comparing various characteristics of SLS and IM specimens showed that SLS specimens have more porosity than IM specimens, and all mechanical properties of both resins tend to decline. On the other hand, compared to the IM specimens, the SLS specimens were confirmed to have higher crystallinity because of a longer process time at high temperature. It was revealed that as a result of that higher crystallinity, the heat deflection temperature (HDT) of the SLS specimens is higher than that of the IM specimens. However, the size of spherulites in the SLS specimens was smaller than that in the IM specimens. It is supposed that this finding is attributable to the fact that the nucleating-agent effect (due to contamination generated during powdering) is stronger than the influence of the process (IM or SLS).

As reported in Chapter 4, when the proportion of short-glass-fiber (SGF) addition (15, 30, 45, and 60 wt%) was taken as a parameter, various properties of the cPBT-SGF specimens were evaluated. In the case proportion of SGF addition was taken as a parameter, tensile strength and flexural strength of the SLS specimen were maximized by SGF addition of 30 wt%; however, impact strength was maximized by SGF addition of 45 wt%. As the proportion of added SGF was increased, the amount of SGF "debonding" also increased, while the amount of resin that adheres to the SGFs decreased and porosity increased. Compared to SGF addition having an insignificant effect on mechanical properties, it significantly improved thermal properties and reduced shrinkage. Moreover, even if SGF was added, it had little effect on the crystallization properties of the powder and SLS specimen.

As explained in Chapter 5, cPBT with addition of 30-wt% SGF was used to evaluate the dependence of the

properties of specimens manufactured by SLS and the influence of laser-irradiation conditions on build direction. The degree of orientation of SGFs in SLS was ranked in descending order of roller-movement direction, vertical direction in the powder-bed plane, and direction of lamination-layer thickness. Moreover, the influence of fiber orientation on mechanical properties, thermal properties, and shrinkage ratio was found to be remarkable. In the case of the double-scan method in SLS, in comparison to the single-scan method, while thermal degradation was suppressed, porosity was reduced, and mechanical properties were improved. Furthermore, in regard to roller-movement direction and lamination-layer thickness direction, the trends of shrinkage ratio differ in the cases of the single- and double-scan scanning methods. Moreover, it was revealed that the SLS specimen formed by double scan (in which the orientation of the fibers is similar to that in the IM specimen) has similar mechanical characteristics to the IM specimen and a high HDT.

In summary, with respect to SLS specimens using PBT (which has very few research examples), we have succeeded in producing specimens of high-strength PBT—which can be used for actual specimens—by using cPBT-based materials.