INTISARI

Pencetakan 3D *Fused Deposition Modeling* (FDM) *multi-material* PLA/TPU merupakan sebuah metode untuk menggabungkan sifat kekakuan *Polylactic Acid* (PLA) dan kelenturan *Thermoplastic Polyurethane* (TPU) dalam satu struktur. Namun, perbedaan karakteristik termal kedua material sering memicu ikatan antarmuka (*interlayer bonding*) yang buruk dan timbulnya porositas (*void*). Penelitian ini bertujuan untuk menyelidiki pengaruh interaksi rasio volume TPU dan metode *post processing* berupa *annealing* bertekanan dengan bantuan *molding* dan beban terhadap sifat mekanis terutama kekuatan tarik (UTS) dan *elongation at break* pada struktur *sandwich multi-material* PLA/TPU.

Spesimen uji tarik dicetak mengacu pada standar ASTM D638 Tipe IV. Desain eksperimen menggunakan metode Taguchi *Orthogonal Array* L16 dengan empat parameter berbeda yaitu rasio volume TPU (12,5; 25; 37,5; dan 50%), suhu *annealing* (25, 75, 125, dan 175°C), waktu *annealing* (10, 20, 30, dan 40 menit), dan beban *molding* (0; 0,8; 1,6; dan 2,4 kg). Analisis Varians (ANOVA) diterapkan untuk mengukur tingkat signifikansi dan kontribusi parameter dan dilanjutkan dengan pengamatan makrostruktur patahan penampang samping menggunakan mikroskop digital.

Hasil penelitian membuktikan bahwa konfigurasi *sandwich* PLA/TPU memicu fenomena *crack bridging* oleh lapisan TPU yang menahan rambatan retak PLA sehingga mencegah kegagalan katastropik. Kondisi optimal untuk mencapai UTS tertinggi diperoleh pada kombinasi rasio TPU 12,5%, suhu *annealing* 75°C, waktu *annealing* 10 menit, dan beban *molding* 1,6 kg dengan rasio volume TPU memberikan kontribusi terbesar yaitu 49,19%. Sebaliknya, elongasi maksimal dicapai pada kombinasi rasio TPU 50%, suhu *annealing* 25°C (tanpa perlakuan panas), waktu *annealing* 10 menit, dan beban *molding* 1,6 kg. Parameter suhu *annealing* berkontribusi 78,53% terhadap penurunan elongasi. Pemberian tekanan optimal sebesar 1,6 kg terbukti paling efektif mendensifikasi struktur dan menutup *void* tanpa merusak geometri material.

Kata kunci: *Fused Deposition Modeling* (FDM), *Sandwich Multi-Material*, PLA/TPU, Rasio Volume, *Annealing*, Tekanan

ABSTRACT

PLA/TPU multi-material Fused Deposition Modeling (FDM) 3D printing is a method for integrating the stiffness of Polylactic Acid (PLA) and the flexibility of Thermoplastic Polyurethane (TPU) within a single structure. However, the differences in thermal characteristics between these two materials often lead to poor interlayer bonding and the formation of porosity (voids). This study aims to investigate the interaction effects of TPU volume ratio and post-processing treatment in the form of pressure-assisted annealing using molding and external load on the mechanical properties, particularly the ultimate tensile strength (UTS) and elongation at break, of a PLA/TPU multi-material sandwich structure.

Tensile test specimens were fabricated according to the ASTM D638 Type IV standard. The experimental design employed the Taguchi Orthogonal Array L16 method with four parameters: TPU volume ratio (12,5; 25; 37,5; and 50%), annealing temperature (25, 75, 125, and 175°C), annealing time (10, 20, 30, and 40 minutes), and molding load (0, 0.8, 1.6, and 2.4 kg). Analysis of Variance (ANOVA) was applied to evaluate the significance and contribution of each parameter. Fracture macrostructure observations were subsequently conducted on the side cross-section using a digital microscope.

The results demonstrate that the PLA/TPU sandwich configuration induces a crack bridging mechanism by the TPU layer, which restrains crack propagation in the PLA layer and prevents catastrophic failure. The optimal condition for achieving the highest UTS was obtained at a TPU ratio of 12.5%, annealing temperature of 75°C, annealing time of 10 minutes, and molding load of 1.6 kg, where the TPU volume ratio contributed the largest effect at 49.19%. In contrast, the maximum elongation was achieved at a TPU ratio of 50%, annealing temperature of 25°C (without heat treatment), annealing time of 10 minutes, and molding load of 1.6 kg. The annealing temperature parameter contributed 78.53% to the reduction in elongation. The application of an optimal pressure of 1.6 kg proved to be the most effective in densifying the structure and closing voids without damaging the material geometry.

Keywords: Fused Deposition Modeling (FDM), Multi-Material Sandwich Structure, PLA/TPU, Volume Ratio, Annealing, Pressure.