EVALUATION OF CYCLO OLEFIN POLYMER AS SABOT MATERIAL FOR HIGH-DENSITY PROJECTILES

ESTEBANNÉ TARANGO*

*Graduate Research Assistant, Department of Metallurgy and Materials Science Engineering, The University of Texas at El Paso, 500 W University Ave, El Paso, Texas 79968

Summary—Assuring the integrity of spacecraft and its occupants are a priority in the field of space exploration. Micrometeoroids and orbital debris are one of the primary threats that affect spacecraft materials due to the high kinetic energies involved with hypervelocity impacts. Improvement of projectile launching capabilities prompts the investigation of adequate materials for the manufacturing of sabots able to carry high-density projectiles without catastrophic failure. Polycarbonate has been the chosen material by the Hypervelocity Team at White Sands Test Facility for sabots on the 0.50 caliber launcher; however, there is a material constraint when the projectile becomes significantly dense and the inertial stresses surpass the yield strength of the sabot material. This research proposes a new polymer material for manufacturing sabots, known as cyclo olefin polymer (COP) with the purpose of successfully shooting the intended high-density projectiles. In this investigation, both polycarbonate and COP were analyzed using tensile and impact testing to observe the differences in their mechanical properties. The experimental details along with the detailed characterization of the materials are presented.

INTRODUCTION

There is an increasing interest in sabot materials for launching high-density projectiles to examine the behavior of spacecraft materials under hypervelocity impact caused by micrometeoroids and orbital debris. The two-stage light-gas-launcher technique is a great choice for simulation of hypervelocity impacts as it is capable of shooting projectiles with defined masses, shapes, and material consistency with velocities as great as 11 km/s [1]. A sabot is a technical device used to support and stabilize the projectile during its passage through the launch tube. Understanding the dynamics of the projectile-sabot and its interaction with the high pressures due to the compression of the light-gas and barrel wall could lead to improved sabot designs and reduce the likelihood of a model failure without degrading the overall performance of the launcher [2]. The sabot must position and support the projectile during the launch, seal the gases from the launch tube, reduce movement of the projectile and, most importantly, should be able to separate from the projectile without causing any disturbance during the flight or damage to the launcher [3]. A typical two-piece sabot used for a 0.50 caliber barrel after final milling is illustrated in Fig. 1.

The first phase of this investigation focuses on mechanical tests such as tensile and impact testing to determine whether the material behavior aligns with the desired properties that are discussed below. A series of analytical techniques were performed using monolithic samples of optical grade polycarbonate and the new suggested material, cyclo olefin polymer (COP) grade 790R, commercialized under the trade names Zeonex® and Zeonor® by Zeon [4]. This phase compares materials by analyzing and understanding their respective mechanical properties and suggests reasons for changes in sabot material when shooting high-density projectiles.

Fig 1. Polycarbonate two-piece 0.50 caliber sabot.

EXPERIMENTAL METHODS

Selection of Materials

During the selection of materials for sabots, a low-density, high-strength material is preferred due to its ability to sustain higher launch forces without risking material failure taking into consideration that a sabot material with low density will always keep the launch package mass at a minimum. Additionally, a material with a low melting point would aid to decrease barrel erosion, which would reduce the wear of the bore wall caused by friction and heating.

Polycarbonate has been the primary material used for sabots since it provides several benefits including reasonable strength adequate for a wide range of projectiles; reduced material costs due to easier manufacturing processes than other plastics or metals; minimal wear on the launch tube; and breaks into less lethal pieces. Cyclo olefin polymer (COP) is a very attractive thermoplastic resin and was carefully selected based on enhanced properties such as outstanding transparency, good heat resistance, low-moisture absorption, and good chemical resistance [5]. A comparison of the two materials is shown in Table 1. Based on performance characteristics, COP is used in a variety of applications; however, high glass transition temperature is a requirement for some applications to keep good dimensional stability under higher temperatures [5-7]. COP is a new material specifically designed for optical applications, and this evaluation is designed to compare it to polycarbonate.

Table 1. Comparison of mechanical properties between polycarbonate and COP [8,9]

Polycarbonate		*Cyclo Olefin Polymer*	
Density	1.20 g/cm^3	Density	1.01 g/cm^3
Tensile Strength	62 MPa	Tensile Strength	71 MPa
Tensile Modulus	2,379 MPa	Tensile Modulus	2,500 MPa
Flexural Strength	93 MPa	Flexural Strength	94 MPa
Melting Temperature	147 °C	Melting Temperature	138 °C

Injection Molder

LNS Technologies, Model 150A PIM-SHOOTER™ injection molding machine was utilized for producing monolithic tensile samples and Izod impact samples by using pellets of COP grade 790R. The pellets were pre-heated for four hours at 130 °C to reduce the amount of air in the pellets per the molding guidelines for the specific grade of COP [10]. Aluminum molds were pre-heated to 150 °C for 20 minutes prior to use. The pellets were then poured into the injection-molding machine and heated in the hopper to 276 °C [10]. Once heated, the molten plastic was injected into the molds to fabricate the monolithic tensile and impact samples.

Heat Treatment

An annealing treatment was applied to all tensile and impact samples of polycarbonate and COP. The annealing temperature profile for polycarbonate was 147 °C and 133 °C for COP for two hours each. A heat treatment process such as annealing is required once a sabot is machined because the treatment releases internal stresses accumulated during the machining process and produces a tougher sabot. Additional crystals are formed during the cool down process, which creates higher stiffness and less damping [11].

Mechanical Tests

Tensile Test. MTS Criterion® System Model 44 test system was used in the experiment utilizing type IV as specified by ASTM D638, *Standard Test Method for Tensile Properties of Plastics* with a test rate of 5 mm/min [12]. Eight samples (four different samples of each material) were analyzed for comparison.

Impact Test. Polycarbonate and COP samples of 65.5 mm x 12.9 mm x 12.7 mm lengths were notched to a depth of 10.3 mm as specified by ASTM D256, *Standard Test Method for Determining the Izod Pendulum Impact Resistance of Plastics* [13]. Izod impact tests were carried out on a Tinius Olsen Model 104 impact tester. All test-pieces were tested with a potential energy of 7.44 J and a pendulum height of 658 mm. Four samples were analyzed from each material.

EXPERIMENTAL RESULTS

Tensile Test

Conventional stress-strain curves are shown in Fig. 3 for optical grade polycarbonate after annealing. Four samples were analyzed; results were averaged on a stress-strain curve. Tensile data for monolithic COP 790R was unobtainable due to equipment complications.

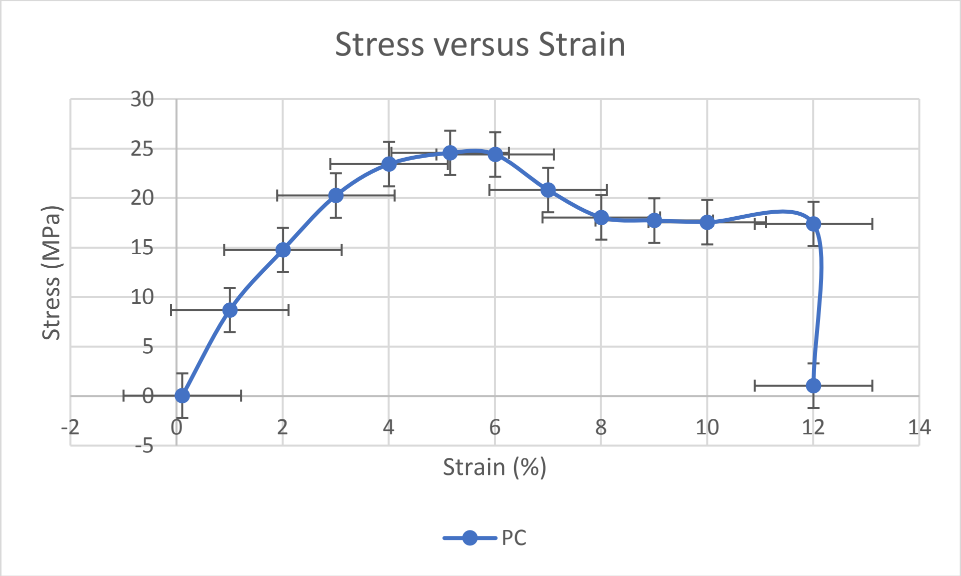

Fig. 3. Monolithic polycarbonate tensile test average results.

Table 2. Tensile test results for monolithic samples of polycarbonate

Sample Number	*Tensile Strength (MPa)*	*Modulus of Elasticity (MPa)*	*Shear Strength (MPa)*
1	25	1006.5	14.4
2	24	1237.9	13.9
3	25	932.9	14.4
4	25	911.9	14.4
Average	24.75	1022.3	14.3
SD	0.433	129.34	0.22

Impact Test

Impact measurements show that polycarbonate has a higher impact resistance and strength compared to COP (Tables 3 and 4). Impact strength is influenced by the design and size of the component, the design of the mold, processing conditions, and the temperature of use [14]. The method of fabrication can also vary the results. The polycarbonate samples were optical-grade machined and manufactured by TRIZOD. The COP samples were made out of pellets using injection molding. The injection-molded specimens were tested in their strongest direction, with the crack propagating at the right angle to the orientation direction, which led to high values. COP samples were observed to be more rigid than polycarbonate, which decreased their impact strength.

Table 3. Izod impact resistance results for monolithic samples of polycarbonate

Sample Number	*Width (mm)*	*Depth (mm)*	*Break Type*	*Impact Resistance (J/m)*	*Impact Strength (J/m^2)*	*Impact Break Energy (J)*	*Pendulum Latched Potential Energy (J)*
1	12.7	10.3	Complete	91.0	8860	1.16	7.44
2	12.7	10.3	Complete	91.6	8880	1.16	7.44
3	12.7	10.3	Complete	90.9	8860	1.16	7.44
4	12.7	10.3	Complete	88.4	8580	1.12	7.44
Average				90.5	8790	1.15	7.44
SD				1.39	141	0.017	

Table 4. Izod impact resistance results for monolithic samples of COP

Sample Number	*Width (mm)*	*Depth (mm)*	*Break Type*	*Impact Resistance (J/m)*	*Impact Strength (J/m^2)*	*Impact Break Energy (J)*	*Pendulum Latched Potential Energy (J)*
1	12.80	10.80	Complete	69.9	6670	1.26	7.44
2	12.80	10.70	Complete	69.3	6670	1.26	7.44
3	12.80	10.90	Complete	70.1	6790	1.28	7.44
4	12.70	10.70	Complete	69.2	6650	1.26	7.44
Average				69.63	6695	1.27	7.44
SD				0.38	55.45	0.009	

CONCLUSION

Based on the experimental data available, the mechanical properties of COP do not appear to exceed those of polycarbonate. Completion of tensile testing will be necessary to evaluate the mechanical properties of COP, as compared to polycarbonate, and its viability as a potential sabot material.

FUTURE WORK

There are several important directions for future work in this area. First, completion of tensile testing is necessary to evaluate its viability as a sabot material. Secondly, implementation of additive manufacturing technologies to compare 3D samples of tensile and impact tests of both polycarbonate and COP should be investigated to observe how properties vary in monolithic versus additive manufacturing samples. Further mechanical properties of COP can be explored using dynamic mechanical analysis (DMA).

Further research should also include computational work for designing sabots and using different infill patterns by utilizing 3D printers. Existing software such as CAD/Solidworks and finite element analysis (FEA) should be considered to calculate different internal stresses and to simulate the process of launching the sabot with a high-density projectile. Finally, producing a composite between COP and polymer would be helpful to observe the reactions and their properties.

Acknowledgment—This research was supported by Jacobs Technology Inc. and NASA. I thank Dr. David Roberson, Associate Professor, Metallurgical, Materials and Biomedical Engineering, at The University of Texas at El Paso for his guidance and the use of the Polymer Extrusion Lab equipment. I thank the Hypervelocity Team at White Sands Test Facility, especially engineers Daniel Rodriguez and Alberto Delgado, for their guidance. I thank my fellow classmate Diego Bermudez for his assistance and support throughout the project. I also thank the AeroBallistic Range Association Student Program for the opportunity to travel to the 70th International Aeroballistics Range Association Conference and present my research.

REFERENCES

1. Lalit C. Chhabildas, *High-Pressure Shock Compression of Solids VIII*. Springer, (2010).
2. Alan C. Mueller and Emerick M. Fernando. *The Dynamics of Projectiles Launched by a Two-Stage Light-Gas Gun*. Kent (WA): QUEST Integrated, Inc. (US); 122 p. Report No.: AD-A274 380 547 (1991 Nov.).
3. A. J. Stilp, Sabot Designs for launching Penetrators and Projectiles. In *High-Pressure Shock Compression of Solids VIII*. High-Pressure Shock Compression of Condensed Matter, (edited by L.C. Chhabildas, L. Davison, and Y. Horie). Springer, Berlin, Heidelberg (2005).
4. M. Yamazaki, Industrialization and application development of cyclo-olefin polymer. *J. Mol. Catal.* A 2004, **213**, 81–87.
5. J. C. Mol, Industrial applications of olefin metathesis. *J. Mol. Catal.* A 2004, 213, 39–45.
6. P. Nunes, P. Ohlsson, O. Ordeig, and J. Kutter, Cyclic olefin polymers: Emerging materials for lab-on-a-chip applications. *Microfluids and Nanofluids*. 2010, **9**, 145-161.
7. Jing Cui, et al. "Synthesis of High-Performance Cyclic Olefin Polymers (COPs) with Ester Group via Ring-Opening Metathesis Polymerization." *Polymers*, vol. **7**, no. **8**, 2015, pp. 1389–1409, doi:10.3390/polym7081389.
8. "Trizod® OP Optical Grade Polycarbonate on Trident Plastics, Inc." *Trident Plastics, Inc.*, plastics.tridentplastics.com/viewitems/all-categories-trade-names-trizod-pc/olycarbonate-trizod-op-optical-grade-polycarbonate.
9. "ZEONEX." *Zeonex.com*, www.zeonex.com/optics.aspx.html#tbl-optics.
10. "ZEONEX." *Zeonex.com*, www.zeonex.com/processing-guidelines.aspx.html.
11. Yury V. Kissin, End-Use Mechanical Properties of Polyethylene Film. *Polyethylene*, 2012, pp. 83–113., doi:10.3139/9781569905210.005.
12. ASTM Standard D256, 2019, "Standard Test Method for Tensile Properties of Plastics," ASTM International, West Conshohocken, PA, 2014, DOI: 10.1520/D0638-14, www.astm.org. (2014).
13. ASTM Standard D256, 2019, "Test Method for Determining the Izod Pendulum Impact Resistance of Plastics," ASTM International, West Conshohocken, PA, 2018, DOI: 10.1520/D0256-10R18, www.astm.org. (2018).
14. T. R., Crompton, *Physical Testing of Plastics*. Smithers Rapra, 2012.