Use Of (PET-G) Material in Mini-Scale Unmanned Surface Vehicle (USV) For Additive Manufacturing

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Abstract: This study aims to determine the material performance of additive manufacturing methods, which enable flexible designs against rapidly changing market needs with a high benefit/cost ratio to meet the increasing defense needs of countries. In addition, the design of an unmanned surface vehicle (UVS) resistant to sea conditions has been realized and produced by additive manufacturing. Advantages such as freedom of design, on-site manufacturing, and low cost in low-volume production have made additive manufacturing methods the focus of today's production method and research topic. Among the additive manufacturing methods, Fused Filament Fabrication (FFF) is the most cost-effective and widely used method. In today's small craft sector, boats made of thermoplastic material are replacing metal hulls and thermosetting matrix composite hull boats day by day. Although composite boats with thermoplastic or thermosetting matrix have limitations in terms of size, it can be said that they are ideal for small USV. In this study, resistance analysis of the forms of 3 different boats was made with finite element and empirical methods. The hull form, which exhibits the lowest resistance value, was produced using the FFF method using PETG co-polymer developed from environmentally friendly PET material. Cruise and field tests were carried out. Material performances were determined to be used in the production of small-scale USVs with the FFF method, and the mini-scale USV was produced using the PETG material with the FFF method. The suitability of PETG material for marine uses was emphasized.

Keywords: Unmanned surface vehicle (USV), Polytene tereftalat glycol (PET-G), Additive manufacturing, Computer fluid dynamics (CFD), Autonomous surveillance

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Nomenclature

USV	:	Unmanned surface vehicle
FFF	:	Fused filament fabrication
CFD	:	Computer fluid dynamics
PET-G	:	Polyethylene terephthalate glycol
ABS	:	Acrylonitrile butadiene styrene
PLA	:	Polylactic acid

1. Introduction

The defense expenditures of the countries constitute an important part of the world economy. A report by SIPRI (an independent international institute conducting research on conflicts, armaments, disarmament, and arms control) shows that in 2021; expanses in the defense industry in The US ($801 billion, accounting for 30%), China ($292 billion, accounting for 14%), India ($76.6 billion, accounting for 3.6%), The UK ($68.4 billion, accounting for 3.2%) and Russia ($65.9 billion, accounting for 3.1%)(Yearbook, 2021). In addition, the defense expenditures of the countries are increasing day by day and the effort to establish technological superiority leads to the use of many resources, especially research and development, in these areas(Ledesma et al., 2022). The importance of efficient use of resources, development of products suitable for the purpose, and the emergence of projects with high cost/benefit ratio can be seen from the unpredictable budget increases of the past defense industry projects(Mehmet Hanefi Topal; et al., 2014). Integrating the gains in defense technologies into our daily lives increases the standard of living of human beings. The benefits of location systems in finding direction and address, the use of existing communication systems for information and information purposes, and the achievements in materials science leading to new products can be given as examples.

Although additive manufacturing technologies were first used in the 1980s, after the patent restrictions remained, they quickly became widespread in the 2010s and started to be used in many different sectors and application areas. Additive manufacturing has advantages such as meeting the rapidly changing market needs with a high cost/benefit ratio, producing personalized and/or customized products, and providing design flexibility. These methods, which were used for trial production in the past, are now able to produce final products. Although we do not have high production speeds, advantages such as freedom of design, on-site manufacturing, and low cost in low-volume production have made additive manufacturing methods today's focus production method and research topic. Additive manufacturing methods produce in layers by slicing the 3D drawing data of the part in layers and processing the solid regions in each slice. Today, it is possible to shape all kinds of materials, including metal, polymer, and even ceramic, with these methods. The parts are processed in layers, these processes involve different techniques such as laser joining or material extrusion. Among these methods, Fused Filament Fabrication (FFF) is the most cost-effective and widely used method(Cole et al., 2020). In the FFF method, polymer materials are used as raw materials.

More than 51% of the materials produced by additive manufacturing are polymer materials. In the FFF method, a heated nozzle moving in the Cartesian coordinate system melts and extrudes the polymer. It is mostly fed in polymer filament form. Equipped with a heated nozzle, the head can move on the X and Y-axis. The movement in the Z-axis is very precise and this determines the layer height. Parts are produced layer by layer in this method.

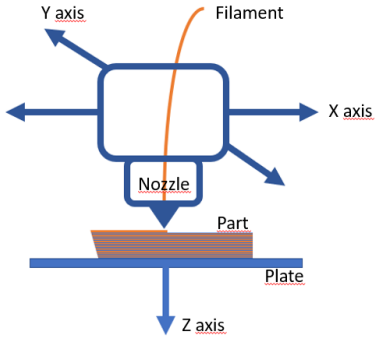


Fig. 1. FFF method in additive manufacturing

In today's small craft industry, the use of polymer composite materials is becoming widespread and replacing metals. Thermoplastic materials are preferred more, and their use is supported due to the recycling problems of thermosettings.



Fig. 2. *A small craft example for patrol boats* (*Ribandhsc.Com*, 2022)

Even though thermoplastic or thermosetting matrix composite boats have size limits compared to metal hull boats, it can be said that polymer materials are ideal to produce small-sized USVs(Yan et al., 2010). In addition, considering that the products we use today are the garbage of tomorrow, the recycling of thermosetting composite boats and synthetic fiber reinforcements is an important problem(Backman & Lidgren, 1986). Humanity is facing this problem more and more every day. The recycling advantages of thermoplastic materials are critical to sustainability. The use of thermoplastic materials with the FFF method creates significant opportunities. Many different thermoplastic materials can be processed with the FFF method. PLA, ABS, PE, PA, PET, etc. thermoplastics. One of these thermoplastic polymers is polyethylene terephthalate glycol (PETG). Developed from PET material, PETG Copolymer has increasing importance in the FFF method thanks to its properties. It has durability, flexibility, high impact resistance, high chemical resistance, ultraviolet and weather resistance, low moisture absorption and gas permeability, odorless, and recyclability(Bhandari et al., 2019; Latko-Durałek et al., 2019). PETG material is easy

to produce with the FFF method and stable products can be produced(Szykiedans et al., 2017). In addition, because PETG is an amorphous and linear polymer, it is an excellent material for extrusion, injection molding, blow molding, and thermoforming(Latko-Durałek et al., 2019).



Fig. 3. *USV boats* (*Unmanned Surface Vehicles USV*, n.d.)

PETG's low crystalline phase content, good mechanical properties, and good chemical resistance make it a good alternative for marine applications(Barrios & Romero, 2019; Srinivasan et al., 2020). Intercalarily, when the advantages of additive manufacturing and thermoplastic materials are combined, mini-scale USV production will create opportunities for the maritime industry. Mini-scale USVs are used for underwater mapping, underwater imaging, minefield detection, combating irregular migrants, territorial waters security, etc. can be used for purposes.

2. Method

Resistance analysis was carried out using finite element methods of boat forms with different principles, such as planing, displacement, and catamaran. The hull form, which exhibits the lowest resistance value, was produced with the FFF method using PETG co-polymer developed from environmentally friendly PET material, and 40 cm-long mini-scale USV sea trials were performed. In numerical analyses, the turbulent flow around the boundary condition is modeled by the Reynolds Averaged Navier-Stokes (RANS) model and the SST Menter k-Ɛ turbulence model.

1.75mm diameter PETG (copolyester) filament of the Azure film brand was used. AzureFilm PETG (Copolyester) filament is a filament that combines the properties of ABS filament (strong, temperature resistant, extremely durable, flexible) and PLA filament (easy to print). It has a density of 1.29g/cm3, 51MPa tensile yield stress, and 68MPa flexural strength. The red colored filament was preferred to make a visual inspection and photographing clearer and easier.

The production of the Mini-scale USV design selected by comparing the data obtained as a result of the numerical analysis was carried out with the Creality cr-200b brand model FFF device, using a 0.6mm diameter nozzle. As production

parameters were obtained as infill rate 25%, layer height 0.2 mm, nozzle temperature 230 °C and printing table temperature 80 °C, and printing speed 40 mm/s.

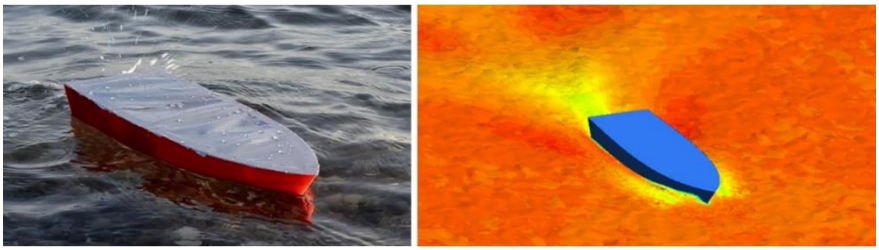


Fig. 4. USV build by additive manufacturing on PET-G material and CFD

3. Results and Discussion

This study shows the numerical prediction of resistance characteristics of three hull models, for different velocity conditions. The resistance characteristics of the hull models were compared in terms of total resistance. For the same hydrodynamic conditions and investigated velocity range, the total resistance values of the catamaran hull model are higher than the others. Planing hull performs the best results. Consequently, this study shows that CFD can be used as a practicable and feasible tool in gaining insight into the various hydrodynamics problems and generating new designs.

PET-G provides superior layer adhesion. It is much more resistant to layer shifting. This feature makes this material very attractive for marine uses. Sea tests prove this situation. Although the outer layer wall thickness is 2 mm, waterproofing has been achieved successfully. In addition, the hull was printed in 2 pieces, the welding points of the hull are quite strong and waterproof.

Table. 1. Resistance results for 3 different boat types.

	Resistance (Newton)		
Velocity (m/s)	Planing hull	Displacement hull	Catamaran hull
1	0,3	0,4	0,45
3	1,7	2,32	2,57
5	5,12	6,38	7,2

4. Conclusion

In this study, the processes of determining the material performance of PET-G material and producing a small-scale USV resistant to sea conditions with additive manufacturing were carried out to emphasize effective benefits. PETG material has great potential for marine use in additive manufacturing with its superior waterproofing. USV produced by additive manufacturing is expected to become widespread soon due to increasing cost concerns and design freedom in the defense industry.

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