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Analysis of the Substitutability of Conventional Technologies in the Design of a Clamping Vise for Measurement Using an Optical Measuring System

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The work deals with the possibility of using additive technology in the production of positioning and clamping device. The designed clamping device will facilitate and accelerate the measurement of samples with inclined or different irregular surfaces. The designed device is manufactured by additive technology using composites. Onyx material reinforced with Kevlar fibers was used as material for composite printing. The designed device should achieve the required properties for the firm and stable clamping of the components during the measurement process, and its weight should be significantly reduced with the use of composite material.

Keywords: Additive Technologies, Composite Materials, Design of a Clamping Vise

1 Introduction

Over the past decade, the additive manufacturing industry has grown by more than 25 % per year. With the increased usage of additive technologies in the industry, the development of new high-performance materials and innovative devices to meet the functional requirements of the industry increased. Currently, devices for the FDM technology can print with filaments such as PLA and ABS, as well as technical thermoplastics such as nylon (PA), polyetheretherketone (PEEK), and polyetherimide (PEI). [1] In the past, additive technologies were mainly used for the needs of Rapid Prototyping for the design and testing of parts before machining and injection mol- ding. Today, additive technologies are utilized for end-use applications in virtually every commercial sector. [2] Designing parts produced by additive technology for end-use applications brings new design difficulties. A signi- ficant number of selected printing parameters, materials, and end-use of the environment constitute an integral part. [1,3]

Despite the numerous benefits provided by additive manufacturing, the majority of plastic parts manufactu- red by this technology are still at the prototype stage. Their application is limited mostly by their lower strength in comparison to commonly used materials. [2,4] Numerous studies have been conducted to improve the me- chanical properties of parts manufactured by additive manufacturing technology. To improve the mechanical properties, reinforcement materials in the form of particles or fibres were added to the printed components. This method has been widely used in processes to improve the strength of conventional composites by creating fiber-reinforced polymers (FRP) [3].

Fused Filament Fabrication technology (FFF) is more commonly called Fused Deposition Modeling (FDM). This technology uses thermoplastic material in the form of fibers. The material is extruded through a heated nozzle and melts during the process. [5] The 3D printer places the material on a print bed where it cools and solidifies. This procedure builds parts layer-by-layer manner. When one layer is completed, the nozzle is raised one layer high or the platform is lowered by the same height [6]. Continuous Filament Fabrication technology (CFF) is similar to the FFF technology, with the difference that the 3D printer includes a second print head that inserts continuous filaments (carbon, glass, or Kevlar) into the manufactured part. [4,6]

Additive technologies can be used for the production of fixtures, the production of which would be econo- mically ineffective if manufactured by conventional technologies. The costs of fixture manufacturing would ex- ceed their benefits. Therefore, these technologies justify their production. This creates many opportunities to use fixtures in practice. [7,8,9]

The fixture is a work-holding device that holds and supports the workpiece, guides the tool, and ensures the mutual position of the parts during assembly or welding. A rigid body in space has six degrees of freedom. For the part to be properly placed in the fixture, all degrees of freedom must be removed from it, and it must be clamped to prevent displacement due to operating forces. [8,9]

Universal fixtures are used for positioning and clamping workpieces of various shapes and sizes. Positioning and clamping elements can be adjusted without the need to replace them. These include, for example, rotary tables, machine vices, chucks, clamping mandrels, etc. [10,11,12]. They are used for clamping technologically and sha- pe-similar parts of different sizes, on different types of machine tools. They are predominantly employed in the piece and small customized production [13,14,15]. After special accessories are added, they can be used in mass production. Universal fixtures are standardized and typified. As a result, they are significantly cheaper compared to special fixtures [13,14,15].

2 Matherials and methods

This work aimed to design a support device for the positioning of samples on the Proto iXRD diffractometer and for the Alicona InfiniteFocus G5 measurement system.

In practice, a problem arose when it was necessary to measure parts with bevelled or differently shaped surfaces. Due to the limited load capacity of the table, it was necessary that the support equipment is lightweight. The maximum load capacity of the table is 4.5 kg.

2.1 Used printer

The proposed fixture was made using the 3D printer Mark Two from Markforged which is depicted in Figure 1. a) The device enables the use of composite fibres to reinforce printed objects. In addition to the main print head, through which molten material is extruded, the printer has a second print head shown in Figure 1. b) that inserts continuous fibres into the manufactured component. [2,4,16]

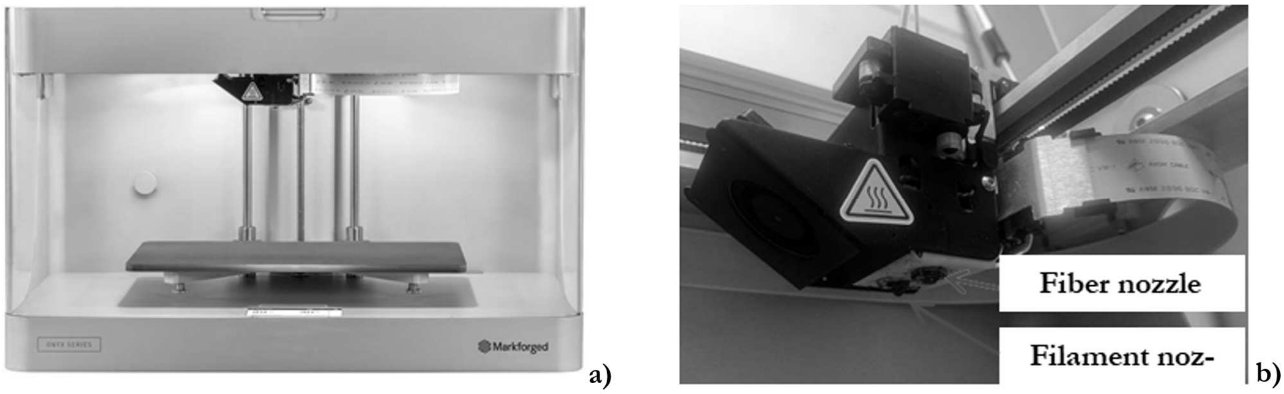


***Fig. 1** a) Printer Mark Two (top3dshop.com/product/markforged-onyx-one-3d-printer), b) Print head*

The used printer has a printing area of 320 x 132 x 154 mm. The resolution of the printer in the Z axis is 100 μm. A nozzle with a diameter of 0.4 mm is used for printing, which guarantees the printing of models with good strength and printing speed. The printer can be controlled either through a computer or the touch panel. [2,5,12].

2.2 Printed material

Onyx was chosen as the printing material. The Onyx material is composed mainly of nylon, which is resistant to many chemicals, including cutting fluids [10,15]. It is a specially designed nylon PA6 copolymer with chopped carbon fibers [17]. These carbon fibers increase the stiffness of 3D printed parts, increase dimensional accuracy, and give the parts a smooth, matte, black surface [18].

Onyx has higher stiffness and holds its shape better under thermal stress compared to most 3D printing ma- terials. Higher stiffness and minimal thermal deformations guarantee less deformation during 3D printing. This minimizes the detachment of the printed part from the print bed. Low material shrinkage and thus low thermal deformations allow components to be printed at the bevel angle of up to 70°, printed without supports. This ensures a high level of dimensional accuracy [18]. Reinforcement with continuous fibres decreases shrinkage and detachment from the print bed because the fibres have sufficient strength to keep the layers flat, i.e., they con- centrate the stresses within the material [19].

This material possesses a three times higher stiffness but a three times lower toughness compared to standard nylon while retaining approximately the same strength [19]. It is highly resistant to abrasive wear but at the same time, it is abrasive. Therefore, it is recommended to print parts that are in contact with other materials, as a result of which they are subjected to greater wear from pure nylon and the remaining structural parts from Onyx [11,12]. It is a material with good machinability. During machining, such as drilling holes and cutting threads, it is vital to ensure that the wall thickness is sufficient to prevent the machining from reaching the filling. Sanding with sandpaper is more difficult than in the case of nylon [10,14]. Similar to nylon, onyx must be stored in an airtight container without access to moisture. Material that has absorbed an excessive amount of moisture might result in printing defects such as printing failure, insufficient material dosing, holes in the top layers, etc. [10,15].

The mechanical properties are listed in Table 1.

Tab. 1 *Mechanical properties of printed material [16]*

Material property	Test Standard	„Tough Nylon´´	„Onyx´´
Young's modulus (GPa)	ASTM D638	0.94	1.4
Tensile strength (MPa)	ASTM D638	31	36
Tensile Strain at Break (%)	ASTM D638	27	25
Ultimate tensile strength (MPa)	ASTM D638	54	30
Ductility after breaking (%)	ASTM D638	260	58
Flexural Strength (MPa)	ASTM D790*	32	81
Flexural Modulus (GPa)	ASTM D790*	0.84	2.9
Flexural Strain at Break (%)	ASTM D790*	-	-
Heat Deflection Temperature (°Celcius)	ASTM D648 Method B	49 140**	145
Density (g/cm^3)	-	1.1	1.18
Impact Strength – sample with notch (J/m)	ASTM D256-10 Method A	1015	334

3 Experimental part

To clamp the samples, a fixture resembling a clamping vice was designed which can be seen in Figure 2. Inclining is ensured by means of a pivot placement. It is possible to set the angle of inclination in the range of 0 to 90°. The scale is used to determine the set position, which is then secured by tightening the locking screw.

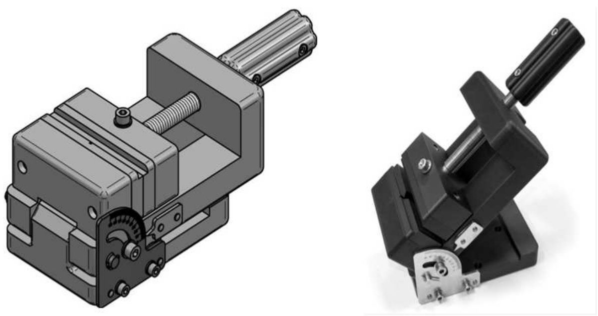


Fig. 2 *Figure 3 3D model of the vise*

Figure 3 illustrates the components of the vise integrated into a single unit. The lower part, the body of the vice, the fixed and movable jaw, and the handle were made using CFF additive technology.

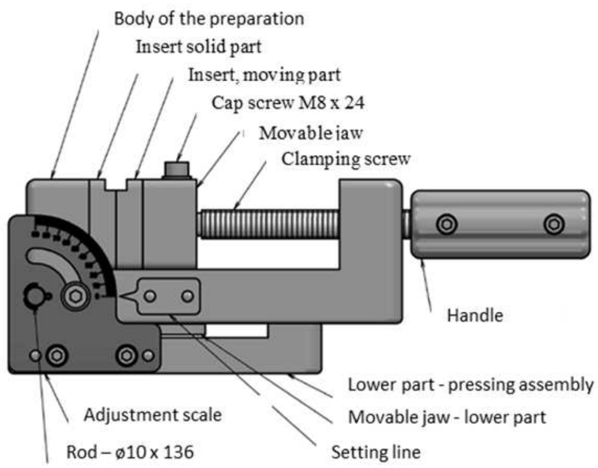


Fig. 3 *Parts of designed vise*

The fixture contains replaceable jaw inserts. These can be easily designed and manufactured by 3D printing technologies to copy precisely the various shapes of the components. Figure 4 shows a replaceable insert in a fixed jaw. It includes a V-notch for clamping cylinder-shaped components and an upper recess for clamping, for example, metal sheets. The metal sheet for setting and securing the position was made by laser cutting from a 3 mm thick stainless steel sheet. This metal sheet contains a scale for precise adjustment of the inclination angle of the vise, which was made by laser engraving.

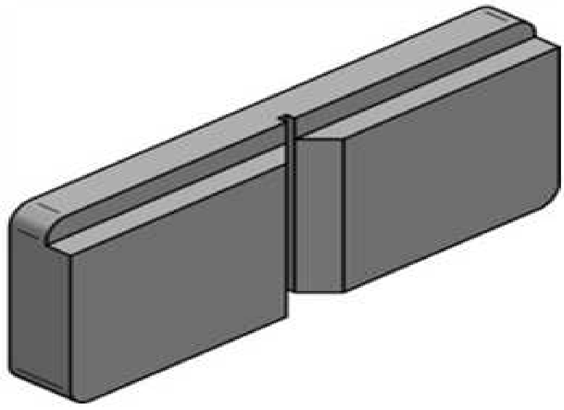


Fig. 4 *Replaceable insert of fixed jaw*

For printing, it was necessary to define individual production parameters in the Eiger software, such as material, device type, support settings, filling type, number of top and bottom layers, number of outer layers, number of reinforcement layers, type of reinforcement, number of concentric reinforcement fibers, the orienta- tion angle of reinforcement fibers. Next, it was required to determine, for the body of the fixture, the position of the reinforcing fibres shown in Figure 5 and the order of the layers; upon completion, the 3D printing process will auto- matically cease due to the requirement to insert the matrix. By adding carbon fibers, a sandwich panel was created inside the component, which contributed to a favourable strength-to-weight ratio. A total of eight layers of isotropic fibres were used, with the rotation angle of the fibres set to 0°, 45°, 90°, and 135°. Four layers were placed in the lower part and four layers were placed as high as possible.

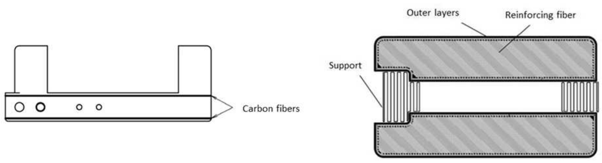


Fig. 5 *Position of continuous carbon fibers*

As depicted in Figure 6 a), it is possible to insert external components into cavities in the component while printing is stopped. To avoid cooling and shrinking of previously printed layers, the pause for inserting external components such as a matrix should be as short as possible. Printing then continues and the inserted matrix is covered with additional layers of material that can be reinforced with continuous fiber. To prevent collision du- ring printing, the top surface of the component inserted must be lower than the nozzle. The cavity must not be higher than the inserted component, because the printing would take place in the air, which would result in defects. Figures 6 a) and b) depict the interior filling of the component as the type with a hexagonal shape with a filling percentage of 50 % for all components.

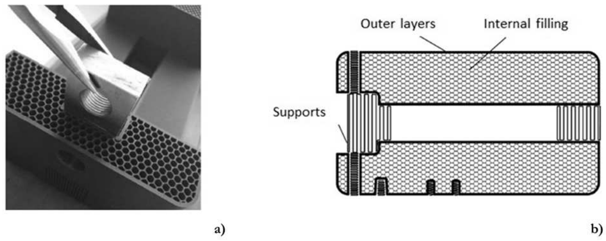


Fig. 6 *a) Inserting matrix into fixture cavity, b) Internal filling*

Brass threaded inserts were used in components where it was necessary to make threads from a structural point of view. These inserts were hot-pressed into the holes made during the printing of the components shown in Figure 7. After pushing the insert with the heated tip of the soldering iron, it was important to hold it in the desired position to prevent it from sliding out of the hole during cooling.

Fig. 7 *Inserting of threaded insert*

4 Results

After printing the parts, removing the necessary supports, and inserting the appropriate threaded inserts and matrixes, the dimensions were measured and then compared graphically for similar devices made of different materials.

4.1 Measurement of dimensional accuracy of 3D printed parts

Individual parts made by additive manufacturing were measured using a 3D scanning 6-axis arm Alwaid ACE 6-20 with an ACE Skyline scanner. The accuracy of this 3D scanner is 15 μm (ALWAID). Figure 8 depicts deviation maps of manufactured components compared to the 3D CAD models. The comparison shows that these deviations of the manufactured components are within ± 0.2 mm. The colour display is dominated by green, which means that deviations are in the range of ± 0.05 mm. The surface of the manufactured components is not smooth and differs from the surface of components made by machining. The influence of additive manu- facturing on the surface of the components resulted in the formation of a texture comprised of small protrusions and imperfections. These imperfections have no effect on accuracy and function, yet the scanner detected them.

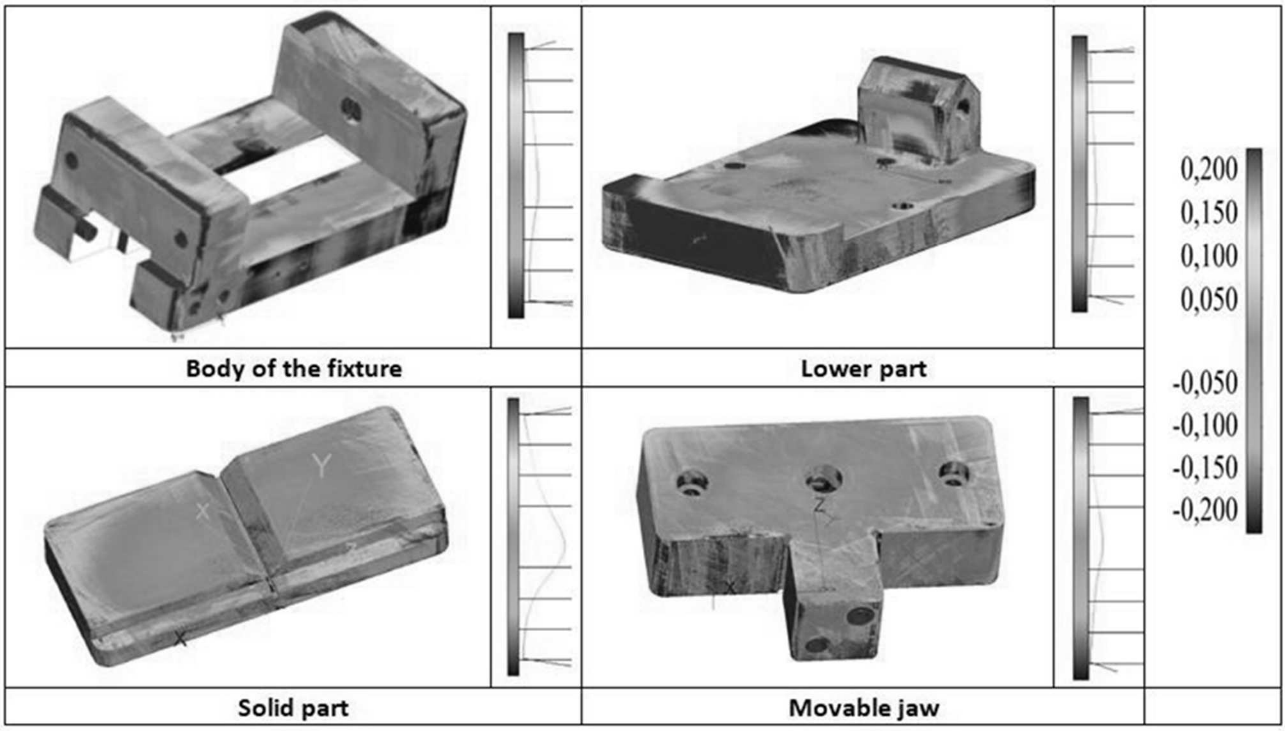
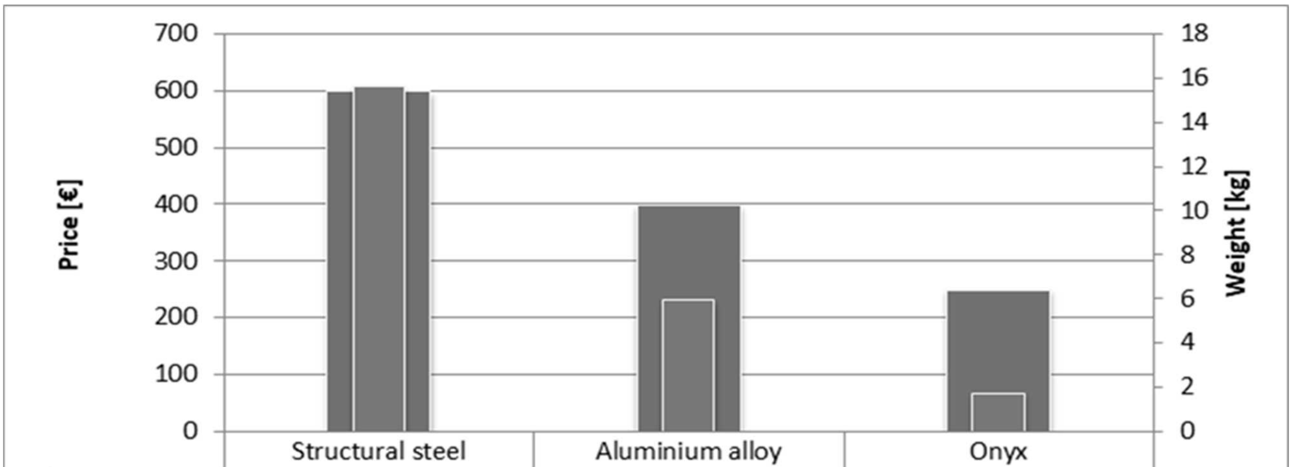


Fig. 8 *Comparison of accuracy of printed parts with models*

4.2 Weight and price of the manufactured device

Graph in Figure 9 depicts the comparison of the cost and weight of vise versions manufactured using conventional technologies from structural steel, aluminium alloy, and additive manufacturing technology using Onyx material. Based on the graph's values, it may be concluded that the additive technology managed to meet the minimum weight requirement for the device. Due to their weight, versions made of structural steel and aluminium alloy surpass the load capability of the measuring equipment table and therefore are unsuitable. Based on a graphical comparison of the approximate cost of conventionally manufactured and 3D-printed versions, the 3D-printed version is the most cost-effective. The higher costs of conventionally made versions are related to the necessity of surface treatment such as anodizing of aluminium alloy and blackening of steel.



	Structural steel	Aluminium alloy	Onyx
Price [€]	600	400	250
Weight [kg]	15,664	5,939	1,746

Fig. 9 *Comparison of price and weight of devices*

5 Conclusion

There are many benefits to be gained from utilizing additive technology in the manufacturing of clamping components for fixtures. One of the most essential benefits is the ability to develop complex fixture designs and geometries. The second advantage is the potential for part consolidation, which occurs when a fixture that is formed using numerous parts can be reconstructed into a single component that has a greater level of complexity. Because of this advantage, the amount of time needed to put together the fixture is cut down significantly. To be more specific, the time savings can vary from 40 to 90 percent, while expense reductions can range from 70 to 95 percent. Furthermore, ergonomics is improved when the components can take on complex organic shapes. These shapes make it simpler and more pleasurable to work with the fixture. Quick responsiveness to the needs of production, easily modified CAD models, more exact tolerance minimizing further machining, fast insertions and adjustments, duplication, and finally digital storage that requires less space in the warehouse also belong to the advantages of additive technology. Furthermore, when compared to conventionally manufactured compo- nents, the average weight of additively manufactured components can be up to 70 percent lower. As a result, the combination of additive and conventional technologies can thus highlight the advantages of both production processes.

However, components created by additive technologies have their limitations and may not be suitable for some applications. Especially in cases when higher working temperatures are required, at which the force-loaded material can be deformed. It is important to note that the strength ratios may exceed the mechanical properties of available materials as well. Therefore, it is important to consider what chemicals will be in contact with the manufactured component as chemical resistance is different for each material. However, the need for a large number of components or extremely simple shapes can make conventional production methods more cost effective.

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