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Preliminary Prototype and Analysis of a Customized Handle for Winding Machine using Fused Filament Fabrication

Sreekanth M P

Assistant Professor, Department of Mechanical Engineering
Vimal Jyothi Engineering College, Chemperi, Kannur, Kerala, India – 670632

{Corresponding author's email: smpcadd@gmail.com}

Abstract – Additive manufacturing transformed the prospect of product development. Customized and individualized product development never be so effortless. In this context, aim here is to develop a preliminary prototype of customized handle for winding machine using in handloom industry. Design of the handle is completed according to the hand anthropometric data of workers. CATIA V5R20 is used for 3D modeling and Analysis. Polylactic Acid (PLA) used as material and FlashForge Dreamer Additive Manufacturing (AM) machine, which works based Fused Filament Fabrication (FFF) is employed for prototyping. Analysis confirms that the design using PLA material is safe as maximum von Moses stress obtained (6.57 x 10^4 N/m^2) is less than the yield strength of PLA material (4.9 x 10^7 N/m^2).

Keywords - Prototype; Customization; Fused Filament Fabrication, Handle, Hand Anthropometry, Additive Manufacturing.

INTRODUCTION

By eliminating tool and reducing wastage of material, Additive Manufacturing (AM) or 3D Printing (3DP) can be considered as one of the most noteworthy development in manufacturing in recent years, which directly prints from Computer Aided Design (CAD) data layer – by – layer [1]. It helps the technology to be a potential player in Industry 4.0 [2]. Fused Filament Fabrication (FFF) or Fused Deposition Modeling (FDM) is an AM technology which usually fabricate the objects layer-by-layer by extruding material through a nozzle [3, 4]. FFF parts can be used in wide variety of applications from unarmed aerial vehicles to 3D Printers [5].

Parry et al. developed a customized crutch grip using 3D scanner, Autodesk Fusion 360, and Stereolithography (SLA) additive manufacturing and recommended that AM is a worthwhile method for fabricating customized Daily Living Aids (DLA) [6]. Additionally, using reverse engineering and FDM additive manufacturing technology, a customized helmet is developed with enhanced comfort. The researchers concluded from the study that the method is suitable for rapid product development and to address the needs of the customer individually [7].

A customized hand orthosis is developed using 3D Scanner and FDM AM machine with a printing time of about 11 hours and lead time of about 1 day, which will be useful for patients [8]. In addition to this, individually customized wrist orthosis was designed using the 3D scanned data of a patient and fabricated by employing FDM technology with upper layer of the orthosis was made of ABS and inner layer was made using TPU (Thermoplastic Polyurethane) [9]. TPU has considerable elasticity and research proved that the flexible inner layer increases the comfort of user [9].

Furthermore, customized orthosis is fabricated using Autodesk Inventor 3D modeling software, 3D scanner, MeshLab software for creating an automated algorithm of 3D scan data, and Raise 3D Pro FDM AM machine [10]. The study concluded that Polylactic Acid (PLA) is strong when compared to other materials used such as Acrylonitrile Butadiene Styrene (ABS), High impact Polystyrene (HIPS), and Polyamide 12 (PA12 – nylon) [10]. Fabrication of customized prosthetic sockets for upper limbs using 3D scanner and FDM process proved the feasibility of fully functional products [11].

Textile industries facing a challenge to deliver more customized products and amalgamation of product, process, and supply chain designs is the feasible to achieve customization in textile industry [12, 13]. At the same time, Chatterjee and Ghosh believed that textile industry can utilize 3DP by exploring its unique capability of manufacturing customized products [14].

From above it can be understood that the research explored the possibility of customized products in various areas including textile industry, especially for fabrics. However, the research is not concentrated on developing customized products for textile machines including for the machines used in handloom industry, which will increase the comfort and productivity of workers. This research proposes a preliminary step towards this. Here, objective is to develop preliminary prototype of a customized handle according to the hand anthropometric data of workers using additive manufacturing technology.

METHODOLOGY

Handle of the winding machine is causing more discomfort based on the consultation with the workers in a handloom industry situated at Kannur. The reasons for discomfort can be concluded from the discussion as follows:

i. The machine is operated by female workers. In general, tools and equipments are made with the logic that “one size fits all”.

ii. The handle is made by wood which comparatively has more wight.

iii. The awkward wrist posture of the workers during the operation.

A. Materials, Software and Machine used

Polylactic Acid (PLA) is the material and Flash Forge Dreamer AM machine which works based on FFF technology is used for fabricating the preliminary prototype of the handle. CATIA V5 R20, a Computer Aided Design (CAD) software used for modeling the handle according to the hand anthropometric data and CATIA V5R20 Analysis and Simulation, a Computer Aided Engineering (CAE) environment in CATIA is used for stress analysis of the handle.

B. Hand Anthropometric Data

Based on the above information, the required hand anthropometric dimensions are identified as palm width (PW) and grip diameter (GD). Fig. 1 shows the winding machine (A) and hand anthropometric data (B and C) collected from workers of selected handloom industry.

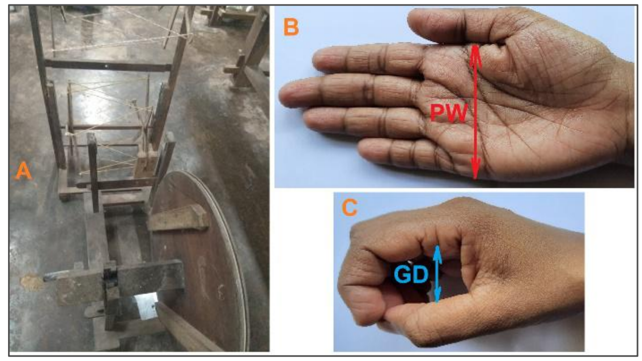

Fig. 1 Winding machine using in handloom industry (A), Palm Width (B), and Grip Diameter (C)

Hand anthropometric data is collected from 65 female workers of handloom industry along with height and are tabulated in the table 1. Table I displayed mean, maximum, and minimum values of the data collected and three designs are proposed to include all the workers within the design and after creating the database, individual design can be printed by exploring the capability of AM technology.

TABLE I
(DESCRIPTIVE STATISTICS OF HAND ANTHROPOMETRIC DATA)

	Height (mm)	Palm Width (mm)	Grip Diameter (mm)
MEAN	1615	76	39
MAXIMUM	1870	86	54
MINIMUM	1400	70	30

B. CAD Model and Prototyping

3D CAD model of the customized handle is prepared based on the collected hand anthropometric data. Fig. 2 shows the 2D proposed design and the details of utilization of collected hand anthropometric data in the customized handle. The elbow shaped handle is for making the wrist in a neutral position and thereby increasing the comfort for users.

The CAD models of customized handles with dimensions displayed in table 1 is completed using part design in the mechanical design environment of CATIA V5R20 3D modeling software. These are shown in fig. 3 (A, B, and C). The small diameter part in the handle, shown at the extreme left end in the fig. 3, will be inserted into the handwheel. Handwheel is attached to the winding machine and it will be rotated to fulfill the intended function.

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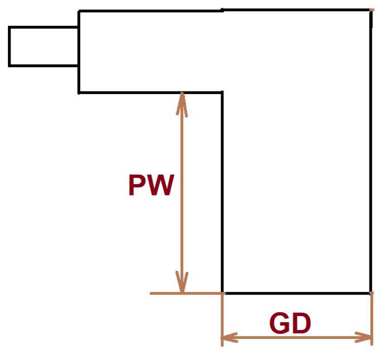

Fig. 2 Proposed design of handle and utilization of hand anthropometric data

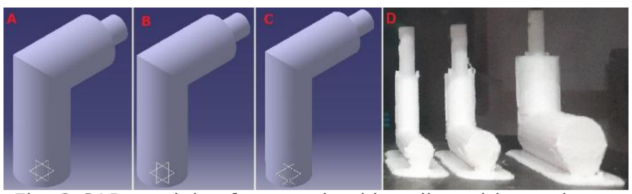

Fig. 3 CAD models of customized handles with maximum (A), mean (B), and minimum (C) dimensions and Prototypes of customized handles (D)

The prototyping of the models is completed using FlashForge Dreamer AM machine and material is selected as PLA with a diameter of 1.75 mm and white in colour. The total Build Time taken was 6 hour and 22 minutes. Fig. 3 (D) displayed the prototypes with minimum, mean, and maximum hand dimensions in the build chamber of the machine surrounded by support material.

Analysis and Discussion

The stress analysis of handle is accomplished by generative structural analysis in the analysis and simulation environment of CATIA V5R20. The handle designed according to the minimum hand anthropometric dimensions (palm width = 70 mm and grip diameter = 30 mm) was used for analysis. It was based on the assumption that the handles with median and maximum dimensions will withstand the same load.

The grip force, 336 N, was identified from research by Koley and Melton [15]. The research reported the grip strength of Indian males and females. Highest value of grip strength was selected for the analysis in this project. This force was converted to pressure force as this was acting throughout the handle surface. By dividing by surface area, 6597.34 mm^2, found that 0.051 N/mm^2 will be acting on the entire surface of the handle. When converted to N/m^2, 0.051 N/mm^2 will be 51000 N/m^2. This is the value used for analysis and is applied on the handle surface. The properties of PLA are tabulated in the table II.

TABLE II
(PROPERTIES OF PLA)

Parameter	Value
Elastic or Young's Modulus	3.6×10^9 N/m^2
Poisson's Ratio	0.3
Yield Strength	4.9×10^7 N/m^2

Fig. 4 (A) shows the constraints and pressure force on the surface of the handle and Fig. 4 (B) illustrates the von Mises stress developed on the handle by applying the above-mentioned pressure force on the handle surface. The maximum von Mises stress attained is 6.57×10^4 N/m^2. The design of the handle is validated based on the von Mises stress criterion of failure. This states that the von Mises stress obtained from analysis should be less than the yield strength of the material [16]. Here the maximum von Mises stress obtained is 6.57×10^4 N/m^2 and yield strength of PLA material is 4.9×10^7 N/m^2 obtained from Matweb 2021 [17]. Obtained maximum von Mises stress is less than the yield strength of PLA. This proved that the design by using PLA material is safe for handles using in winding machine in the handloom industry.

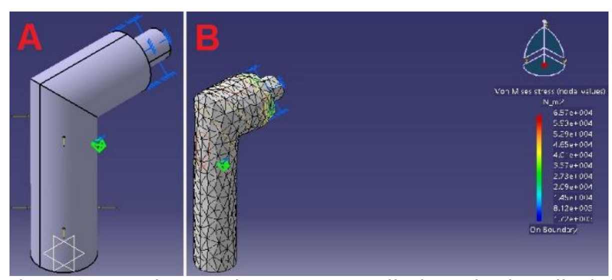

Fig. 4 Constraints and pressure applied on the handle (A) and von Mises Stress (B)

When using hand tools, it is necessary to have a neutral arm and wrist posture for improving the comfort of users [18]. The customized design of handles presented in this research considered this aspect. Refer the figure shown in fig. 5 which illustrated the wrist posture of existing wooden and customized handles (used representative images, not in the real environment). This confirms that customized handles are bringing the wrist in a neutral position and in turn enhance the comfort of workers who uses the winding machine. Another contributing factor to the comfort is the reduced weight of customized handle (PLA) when compared to the wooden handle.

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RECOMMENDATIONS

Design and fabrication of handles based on minimum, mean, and maximum hand anthropometric data are completed. However, individual customization can be done through necessary alterations with respect to individual's palm width and grip diameter in the existing CAD models. By exploring the possibility of AM technology, product can be delivered within a short span of time.

Fig. 5 Wrist postures of existing and modified handles

CONCLUSIONS AND LIMITATIONS

A customized handle using for winding machine according to the hand anthropometric data of workers from handloom industry is developed. Palm width and grip diameter of 65 female workers are collected. By adopting AM technology, customized products can be developed within a reasonable time. Similar strategy can be applied to similar hand tools for enhancing comfort of users. Preliminary prototype is developed in this research and the hand anthropometric data can be collected from more workers and the accuracy of data can be enhanced.

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