An evaluation of some specifications of turbine blades made by 3D printing and machining on CNC milling machines

PHAM HOANG ANH, LE HONG KY
Mechanical Department
Vinh Long University of Technology Education
73 Nguyen Hue Street, Vinh Long City, Vinh Long Province
VIETNAM

Abstract: - This paper presents the research results on manufacturing turbine blades in turbocharger machined on Haas VF2 module TRT 160 5-axis CNC milling machine and by 3D printing method on Metal 3D printer HBD-280 series with the same material AlSi10Mg. The research sample is the compressed turbine blades in the HX40W turbocharger mechanism. CAD data files for machining programming and 3D printing of turbine blades are scanned from an ATOS Core 80 scanner with GOM and Geomagic Design X softwares. Some specifications of the two manufacturing methods are also presented. Research results show that the error of average diameter and surface roughness of 3D printing method is larger than that of machining on a CNC milling machine.

Key-Words: - 3D printing, CNC milling, Rapid prototyping, Surface roughness, Turbine blade

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1 Introduction

Turbocharger for engines is widely used not only in the field of motor vehicles but also in the marine and aviation fields. The turbine blade of the turbocharger is a part with a complex contour, freeform surface without regularity, and there are no studies on geometric modeling, so it cannot be designed with a common software [1-6]. Previously, the manufacture of turbine blades was mainly by casting in metal molds [7-9]. Currently, it is possible to design turbine blades by reverse engineering from the original model through specialized scanning equipment, and after processing and editing with software, the desired design file will be obtained [10-11]. Studies [12-16] show that complex surfaces such as turbine blades can be machined on 5-axis CNC Milling machines. Authors Nguyen Chi Thong and Le Trung Hau have published research results on the influence of technological parameters on the accuracy of diameter and surface roughness of compressed turbine blades in the turbocharger mechanism machined on HASS VF2 module TRT 160 5-axis CNC Milling machines[17]. In general, although it is possible to process turbine blades on 5-axis CNC Milling machines, in terms of economic and technical criteria, it has not yet replaced the casting method in the traditional metal mold. Today, the technology of Additive Manufacturing (AM) or 3D Printing using developed metal materials is considered a breakthrough in the manufacturing technology industry. AM/ 3D printing is not only applied to rapid prototyping, but this technology is also applied in many fields such as the automotive industry, aerospace and biomedical engineering to manufacture metal parts for direct use [18]. From the design file, complex structural parts such as turbine blades can be manufatured by AM technology through the following basic steps: Printing, cleaning and sintering [19]. Selecting which method to manufacture turbine blades is an issue that requires scientific research and evaluation.

2. Research sample and measuring device

2.1. Specifications of turbine blades

The turbine blade model selected in this study is a compressed blade part in the HX40W turbocharger mechanism (Fig. 1a).

2.1.1 Materials

The study used AlSi10Mg as the material for making turbine blades. It is a typical casting alloy with good casting properties and is commonly used for casting parts with thin walls and complex geometrical shapes. AlSi10Mg is a material with great strength and hardness, so it is suitable for parts subjected to high-speed working loads. AlSi10Mg components are ideal for applications that require a combination of good thermal properties and low weight such as turbine blades.

2.1.2 Geometric parameters

Coordinate Mesuring Machine (CMM) is used to determine the average value of diameters *Ø1* and *Ø2* at 3 measurements and the average value of large blades as Fig. 1. The measurement values and the average diameter of the HX40W compressed turbine blade model are summarized as shown in Table 1.

Table 1. Diameter measurement results of turbine blade model.

Measurement position	Measurement results (mm)			
	1st time	2nd time	3rd time	$Ø_{AvS}$
Ø1	59.9999	59.9998	60.0001	59.9999
Ø2	84.5002	84.5003	84.4998	84.5001

1.2.3 Surface roughness

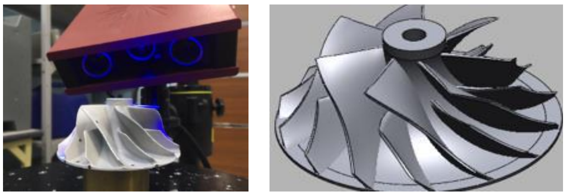
The study used the Mitutoyo SJ-210 roughness meter to determine the surface roughness of 3 large blades (Fig. 2). The measurement values and average value of surface roughness of the HX40W compressed turbine blade model are summarized as shown in Table 2.

Table 2. Surface roughness measurement results of turbine blades.

1st time		2nd time		3rd time		Overall mean	
Ra	*Rz*	*Ra*	*Rz*	*Ra*	*Rz*	Ra_{AvS}	Rz_{AvS}
2.655	15.453	2.447	15.277	2.734	13.116	2.612	14.615

2.2 Turbine blade design

The study used ATOS Core 80 scanner and GOM Inspect software to generate point cloud data from the sample HX40W compressed turbine blades (Fig. 1a). After processing point cloud data with Geomagic Design X software, a CAD data file can be created for machining and manufacturing turbine blades as Fig. 1b [21].



a) b)

Fig. 1. Designing turbine blades from samples

3. Machining turbine blades on CNC milling machines

Turbine blades are machined through 4 operations:

Operation 1: Turn the positioning part and clamping for the next operations, drilling holes smoothly. HAAS TL2 lathe machine.

Operation 2: Milling and breaking the cylindrical workpiece to create the designed workpiece shape and widen the hole after drilling. HAAS VF3 Milling machine.

Operation 3: Finely milling the Turbine blades on Haas VF2 model TRT 160 5-axis CNC Milling machine with cutting speed V = 60(m/min), feedrate S = 0.24(mm/rev) and cutting depth t = 0.35(mm), Fig. 2, [17]. Programming and simulation of machining Turbine blades with Matercam software, machining on Haas VF2 model TRT 160 5-axis CNC Milling machine corresponding to finishing work. Some important factors to determine: machining workpiece, feedrate strategy, order of machining strategies, cutting mode, cutting tool when machining. In this operation, simultaneous 5-axis feedrate paths are used throughout the programming process. Three steps are performed, including: Finishing of turbine blades, finishing of cylindrical surfaces and machining of rounded corners. The program Gcode is transferred by POSTPROCESSOR to the CNC machine for processing.

Operation 4: Cutting off the positioning and clamping is done on a universal lathe.

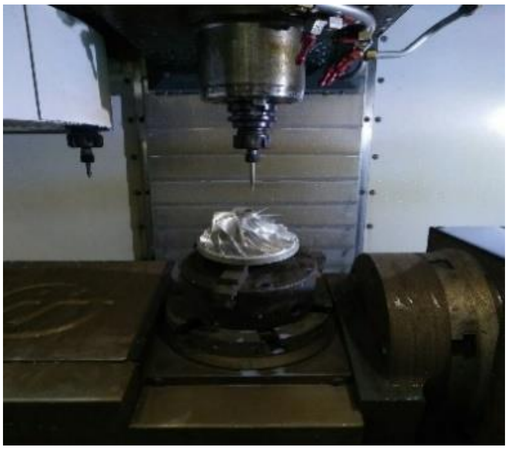


Fig. 2. Machining turbine blades.

4. Manufacture of turbine blades by 3D printing method

Turbine blades are manufactured by 3D printing method using Metal 3D printer HBD-280 series [22] controlled by Voxeldance additive software (Fig. 3b) also with AlSi10Mg material. The forming chamber is initially filled with an inert gas to minimize oxidation of the AlSi10Mg and then heated to the optimum forming temperature. A thin layer of metal powder is spread on the printing bed and a high-powered laser scans the cross-section of the part, fusing the metal particles together and creating the next layer. When the scanning is complete, the bed moves down by one layer thickness and the coating spreads another thin layer of metal powder as shown in Fig. 3a. The process is repeated until the entire part is completed. After printing, cleaning and separating the part from the printing bed, the turbine blade product is obtained as Fig. 5. Since metal 3D printing supports are shaped with the same material as the printed part and are always required to minimize warping and distortion that can result from high processing temperatures. When the barrel cools to room temperature, the excess powder is removed and the product is heat treated while still attached to the bed, reducing any residual stress.

a) b)

Fig. 3. Turbine blade 3D printing process

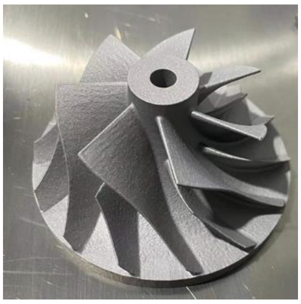
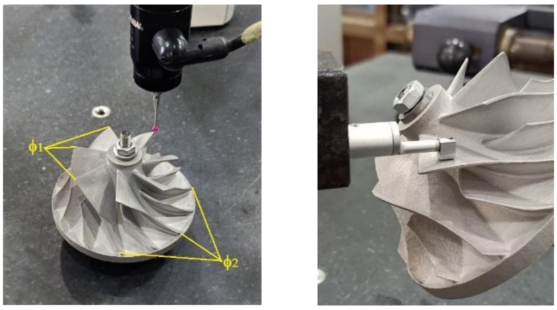


Fig. 4. Product of turbine blades after 3D printing

5. Results and discussion

After machining the turbine blades on a CNC milling machine (Fig. 2) and manufacturing it by 3D printing method (Fig. 3, Fig. 4), similar to the sample part, a CMM coordinate measuring device and SJ-210 Mitutoyo roughness meter (Fig. 5a, Fig. 5b) are used to measure diameters (*Ø1, Ø2*) and surface roughness.



b) c)

Fig. 5. Measuring some specifications of 3D printing product of turbine blades

5.1 Diameter *Ø1, Ø2*

Measurement results of diameters (*Ø1, Ø2*) on 3 long blades with average values ($Ø1_{AvCNC}$, $Ø2_{AvCNC}$) and ($Ø1_{Av3D}$, $Ø2_{Av3D}$) corresponding to 2 machining methods as shown in Tables 3 and 4. The graphs show the respective values as shown in Fig. 5a, Fig. 5b.

Table. 3. Measurement results of large blade diameter of turbine blades machined by CNC milling machine

Measurement position	Measurement results (mm)			
	1st time	2nd time	3rd time	$Ø_{AvCNC}$
Ø1	59.981	60.002	59.992	59.9918
Ø2	84.501	84.492	84.592	84.5280

Table. 4. Measurement results of large blade diameter of turbine blades manufactured by 3D printing method

Measurement position	Measurement results (mm)			
	1st time	2nd time	3rd time	$Ø_{Av3D}$
Ø1	60.0324	60.0050	60.0039	60.0138
Ø2	84.3787	84.4656	84.2545	84.3663

Table. 5. Average diameter error of the 2 machining methods compared with the model

Measurement position	Measurement results (mm)			
	$Ø_{AvCNC}$	*Error*	$Ø_{Av3D}$	*Error*
Ø1	59.9918	-0.0081	60.0138	0.0139
Ø2	84.5280	0.0279	84.3663	-0.1338

Table 5 shows that the average diameter size error ($Ø1_{Av3D}$, $Ø2_{Av3D}$) of the 3D printing method is larger than when machining on a CNC milling machine ($Ø1_{AvCNC}$, $Ø2_{Av3D}$). This error can be overcome when using a metal 3D printer with higher machining accuracy as well as in calculating CAD design files that note the shrinkage of the part after printing and sintering at high temperature.

5.2 Surface roughness

The results of surface roughness measurement (*Ra*, *Rz*) together with the average values (Rz_{AvCNC}, Ra_{AvCNC}) and (Rz_{Av3D}, Ra_{Av3D}) are as shown in Tables 6, 7. The graph shows the average roughness of 3 times measured on the same surface, the same blade of the turbine blade machined on a CNC milling machine (Rz_{AvCNC}), 3D printing (Ra_{Av3D}) compared to the sample as shown in Fig. 5.

Table. 6. Surface roughness measurement results of turbine blades machined on CNC milling machines

1st time		2nd time		3rd time		Overall mean	
Ra	*Rz*	*Ra*	*Rz*	*Ra*	*Rz*	Ra_{AvCNC}	Rz_{AvCNC}
1.408	7.420	1.636	6.534	1.656	6.079	1.567	6.678

Table. 7. Surface roughness measurement results of turbine blades manufactured by 3D printing method

1st time		2nd time		3rd time		Overall mean	
Ra	*Rz*	*Ra*	*Rz*	*Ra*	*Rz*	Ra_{Av3D}	Rz_{Av3D}
3.826	17.570	3.239	17.208	3.577	19.660	3.547	18.146

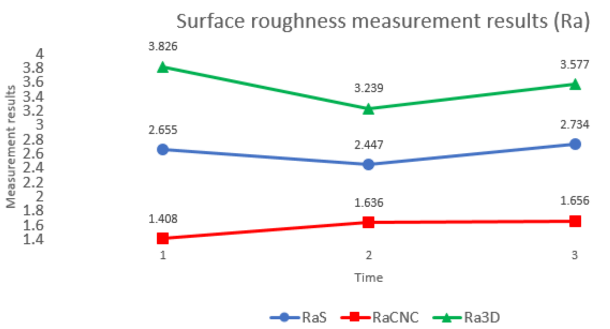


Fig. 6. Turbine blade surface roughness is machined on a CNC milling machine, 3D printing compared to the model

Tables 6, 7 and Fig. 6 show that the *Ra* surface roughness of the 3D printing method on the Metal 3D printer HBD-280 series is larger than that of the model as well as when it is processed on the Haas VF2 module TRT 160 5-axis CNC milling machine. It is completely similar with the measurement value *Rz*. This difference can be completely overcome when machining by sandblasting or using a metal 3D printer with higher machining accuracy.

4 Conclusion

From the research sample of a compressed turbine blade in the HX40W turbocharger mechanism, the ATOS Core 80 scanner with GOM and Geomagic Design X softwares were used to create CAD data files for machining programming and 3D printing of turbine blades. Haas VF2 module TRT 160 5-axis CNC milling machine and 3D printing on Metal 3D printer HBD-280 series were used to manufacture turbine blades with the same material AlSi10Mg. Research results show that the error of average diameter and surface roughness of 3D printing method is larger than that of CNC milling machine. In which, the surface roughness when machining on a 5-axis CNC milling machine is smaller than that of the sample. Although metal 3D printing method is not expected to replace most traditional manufacturing methods, its outstanding features are seen as a breakthrough in the manufacturing industry, especially for parts with thin walls and complex geometries, subjected to high-speed working loads, requiring a combination of good thermal properties and low weight, such as turbine blades.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Author Contributions:
Pham Hoang Anh has organized and executed The machining turbine blades on CNC milling machine and the manufacture of turbine blades by 3D printing method.
Le Hong Ky was responsible for writing articles and liaising with the journal.