CAD Modelling: Light Weight Composite Centrifugal Rotor Manufacturing for Energy Efficiency

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The outcome of the study is reducing the weight of a centrifugal rotor by manufacturing one out of CFRP composite. The paper presents the design study results obtained for the composite centrifugal rotor mold. CAD design of the rotor assembly and the mold were performed and one 1:2.5 scale mold for a single blade was manufactured. Mold material selection study, was performed based on critical requirements related to advanced composite processing and cure conditions. The selected mold material was epoxy Necuron material(s). The 1:1 scale 3D model mold section was designed and obtained in ABS plus using 3D printer.

Keywords: Composite materials, Necuron, CAD modelling, 3D printer

Knowledge based engineering is a complex concept that increases the productivity and product quality in any industry. Computer aided designs have been applied in many industrial sectors, the mechanical sector being the largest user of CAD modelling. Applications include milling, turning, punching, etc. The second largest sector using CAD is the architecture, engineering and construction (AEC) sector and followed by others like electronics engineering and apparel industry. Computer Aided Design (CAD) involves the use of computer hardware and hardware software to generate design drawings, allowing the designer to produce very accurate and realistic images of products to be manufactured. Today, the application of knowledge based engineering includes design (CAD), analysis (FEA – Finite Element Analysis), simulation (CAS – Computerized Analysis & Simulation), optimization, manufacturing, and support (CAPP) where CAD is the foundation for the rest of the cycle. The operator will generate CAD construction drawings starting from sketches. Basically, a CAD program draws objects using x, y coordinates. Current systems, mostly for mechanical products are 3D systems who are spreading towards other sectors. 3D modelling can be Wire Frame, Surface Modelling or Solid Modelling [1]. *Wire Frame* modelling was the first attempt to represent a 3D model, being inadequate, with many drawbacks in precision, adequacy of representation, etc. Here, a 2D-wire frame model is built by forming the 'skeleton' of the part, namely only edges. This method is used now as an intermediate step for building a surface or a solid model. The *surface modelling* is used for designing the skin of the part. Surface modelling is using mainly NURBS (Non-uniform rational B-spline mathematical modelling) [1], which is capable of modelling nearly every industrial part, airplane and automobile surfaces, shipbuilding, plastic parts, metallic parts, etc. This mathematical modelling allows creating surfaces, option which is not available in solid modelling. Models are created by general sweeps along curves, using one or multiple rails lofted bodies, blends with circular or conical cross sections and surfaces that smoothly bridge the gaps between two or more bodies. As for the *Solid Modelling*, it is considered to offer the fullest representation of a part, combining modelling and topology. Usual operation of solid modelling includes 2D and 3D wireframe models, swept, lofted and revolved solids, Booleans as well as parametric editing. A strong characteristic of Parametric and Feature based solid modelling system concerns the assembly modelling capabilities, which provide a top-down or bottom-up, concurrent product development approach. Parts are mated or positioned and are associative. Some of them allow extremely large product structures to be created and shared by a design team [1]. Also, using rapid prototyping machines, 3D model can be printed. It is a fast way for a designer to communicate ideas, assisting the development process.

Experimental part

SolidWorks and CATIA were used for the first CAD design of the rotor at a 1:1: scale (fig. 1a). SolidEdge ST4 was used for 1:1 scale rotor mold as well as for the 1:2.5 scaled mold (section of the rotor mold) for one composite impeller manufacturing. Mechanical operations were used for manufacturing the 1:2.5 scale Necuron mold, including milling, drilling and polishing. Dimension Elite 3D printer (table 1 for specifications) was used for the 1:1 scale rotor mold sector manufacturing using ABS material. The printer uses ABSplus modelling materials, production-grade thermoplastics that are durable enough to perform virtually the same as production parts [5]. ABS results from copolymerization of three components, acrylonitrile, butadiene and styrene. Advantages of ABS are high stiffness, UV resistivity and impact resistivity, ease of processing, good abrasion resistance and dimensional stability. From the disadvantages of this material, low solvent resistivity (aromatic solvents, ketones and esters) can suffer from different efforts, it can be easily scratched and continues to burn after the flame was removed [6].

Table 1
DIMENSION ELITE TECHNICAL DATA [5]

Layer thickness	0.178 to 0.330 [mm]
Support structure	Soluble
Tensile strength	37 [MPa]
Tensile elongation	3%
Flexural stress	53 [MPa]
Heat Deflection	96 [°C]
Build Size (X x Y x Z)	203 x203 x 305 [mm]

Results and discussions

The overall goal of the study is manufacturing of a composite centrifugal compressor rotor/ impeller using the autoclave technology. CAD modelling and material

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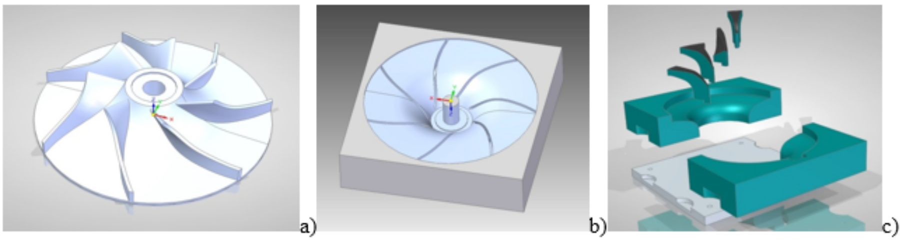

Fig. 1. a) CAD modelled centrifugal rotor; b) Boolean operation on the model, c) Exploded operation of a mold segment

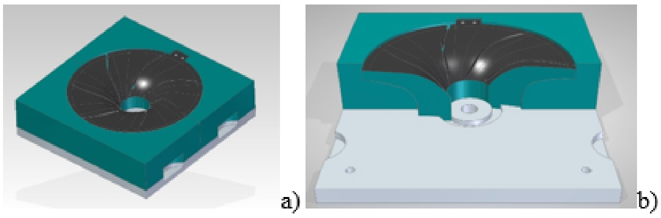

Fig.2. a) CAD of block-mold; b) Section of the 1:1 Scale mold placed on the aluminum support plate

selection (both of the mold and composite materials) were performed taken into account the technology requirements. In a first step the 1:1: scale rotor CAD was designed (fig. 1a). After the model was created, the modelling for the 1:1 mold (fig. 2a) and afterwards the 1:2.5 scaled Necuron mold were realized (fig. 3). For the later, the two Necuron materials [4] subjected to mechanical operations were Necuron 651 and 1001. The 1:1 scale section of the mold was performed using 3D printer with an ABS material. The final 1:1 mold manufacturing material is Necuron 700 [4]. The 3D model of the rotor was used as entry data for block-mold design. The modelling of the mold started with the Boolean operation from the rotor (fig. 1b). Figure 1c presents the exploded version of a sector from the final 1:1 scale mold for the composite centrifugal compressor rotor/ impeller.

The next step after the Boolean operation was dividing the block into segments (2 segments forming a blade and a separator between the parts that form the blade). After dividing into 21 separate segments (three for every blade – two forming the blade and one separator), the assembly of the block-mold was realized (fig. 2). The material that will be used for the block-mold is Necuron 700 (green), and the support base material from aluminium (grey). The black colour represents the composite material that will be placed over the mold.

Selection of materials (Necuron family [2-4]) for the 1:1 and likewise the 1:2.5 scaled molds of the centrifugal compressor rotor/impellers, was done based on a set of requirements imposed by the centrifugal compressor rotor/ impellers materials (advance composites) processing and cure stages.

The mold material as to provide:

- a low CTE (coefficient of thermal expansion, $50x10^{-6}$/K) in order to avoid thermal stress concentrations do to mismatch between CTE of the mold material and CTE of the processed material: the composite, which have a near zero CTE (i.e. $1.1x10^{-6}$/K);

- good machining, easy mechanical work which implies lower time and costs associated to the manufacturing process;

- high compression strength, high stiffness, wear resistance and low absorption of humidity;

- good dimensional stability up to high temperatures (i.e. 120°C) used for curing during composite materials processing;

Materials from Necuron family [2] are suitable for different industrial applications: insulators, copy models, tools for serial production, rollers, housing parts, clock-gearing, plain bearings, gearwheels, molding tools, seals, etc.

Starting from the CAD model of the mold, a 1:2.5 scale mold of one impeller was realized (fig. 4), out of Necuron (both 651 and 1001). Due to the *small* scale size, the 1:2.5 scale mold had to be performed out of three separated components (fig. 3a, 3b, 3c). The black colour face represents the part where the composite material will be placed, forming after polymerization, the composite blade. To keep the components in place, 8 pins (Ø 3.2mm and 9mm length) were manufactured out of aluminium and used for 1:2.5 scale mold closing.

Different mechanical processes were used like milling, drilling and polishing. The milling of the mold was realized using a DMU Duckel Maho CNC milling machine [3]. The milling regimes are presented in table 2 below.

A 1:1 scale section of the mold was performed using 3D printer with an ABS material. The purpose here was studying the possible defects or some irregularities in the manufacturing process which could not be visible in CAD. For the 1:1 scale mold sector, the blade section was formed out of two components and two separators, on each side of the blade components, a support disc and support plate. Each component has at least one planar surface, for ease of components removal. The models are printed from the bottom up with precisely deposited layers of modelling and support materials. The support material can be easily removed in water based solutions. Printed models can be drilled, tapped, sanded and painted [4]. The printing process starts with heating the printer chamber up to 72°C and the extrusion head up to ~270°C. When the temperature has reached the above mentioned value, the support material is layer printed, forming a frame for the ABS. The ABS can

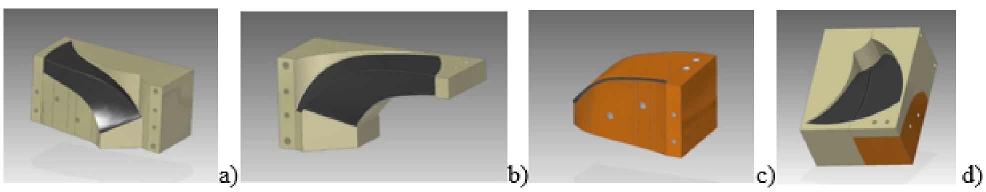

Fig. 3. a),b),c) Components of the mold; d) Mold Assembly (Brown–Necuron 651; Light brown–Necuron 1001)

Table 2

MILLING REGIMES FOR 1:2.5 SCALE NECURON MOLD MANUFACTURING

Cotter milling		Planar milling	
Speed	4000 [rpm]	Speed	1200 [rpm]
Cutter	2.5 [mm]	Cutter	80 [mm]
Feed rate	200-300 [mm/min]	Feed rate	200-300 [mm/min]

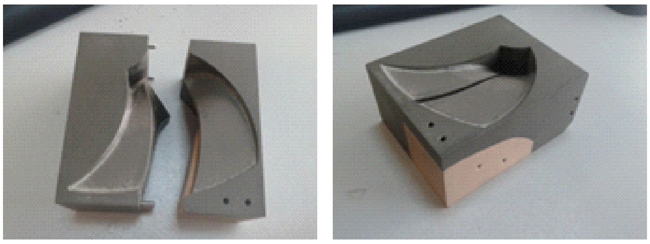

Fig. 4. Final Necuron 1:2.5 scale mold for one impeller, started from CAD model (fig. 3)

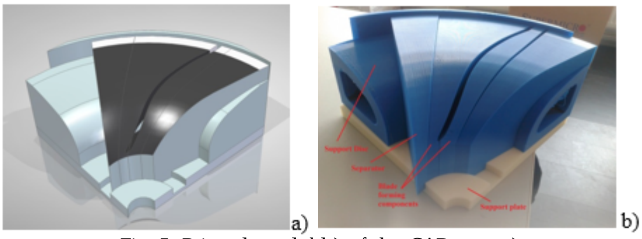

Fig. 5. Printed model b) of the CAD part a)

be printed after the support material has been deposited, or in turns with support material.

CAD model and the printed model are shown in figure 5a and figure 5b, respectively. The gap inside the support disc was left on purpose, to reduce material consumption.

The final 1:1 scale mold for the composite centrifugal compressor rotor/ impeller is manufactured out of Necuron 700 material and the support plate out of aluminium.

Conclusions

The paper presented the results obtained with respect to design of a mold for the manufacturing process of a composite centrifugal rotor. The design for the rotor, 1:1 and respectively 1:2.5 scale mould for the composite centrifugal compressor rotor/impellers CAD models were obtained using SolidEdge ST4, CATIA, SolidWorks, 3D solid modelling software. CAD models resulted comprises issues related to the technological manufacturing steps, taken into account during design study. The mechanical work operation results showed quality results with respect to complex shape part manufacturing (1:2.5 scaled mould performed in Necuron), good tolerances with the CAD model, high performances answering to requirements related to composite processing: thermal resistance, low coefficient of thermal expansion and high quality surface (roughness). The 1:1 scale 3D model of a section of the mold was designed and obtained using 3D printer. Both 1:2.5 and 1:1 scale moulds were designed comprising solutions for an easy extraction of the composite part after manufacturing process. The outcome of the overall study is reducing the weight of a centrifugal rotor by manufacturing one out of composite material, using autoclave technology.

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