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MANUFACTURE OF TRANSMISSION HOUSING BY CONTACT LAYER TECHNIQUE USING VACUUM BAG

The article presents an experimental procedure for making a single product - a gear housing, by the hand lay-up technique using a vacuum bag, as part of an adaptation project. The applied technological procedure included using the original element as a model to produce a mold, the production of the mold and the production of two elements from two alternatively reinforced laminates (a chopped-strand mat and a plain-woven fabric), by the hand lay-up method. On the basis of the observations made during the technological procedures and based on evaluation of the manufactured products, it was stated that the hand lay-up lamination technique with additional use of a vacuum bag is a very good and simple method of making single products. The use of vacuum prevents the occurrence of defects typical for classic manual lamination, such as delaminations, closed air bubbles, or (especially) lack of adhesion in low-radius curved areas. It was also found that the original solution consisting in removing the semi-finished product in the form of a part of the hardened stack from the model/form and continuing the lamination of the remaining layers outside the model/form is effective. It has no visible impact on the quality of the product and significantly facilitates demolding. An important issue during the application of vacuum bag assistance is proper selection of the amount of catalyst for the resin. This should be preceded by measuring the room temperature in which the process is carried out and the time of the hand lay-up lamination process - the number of layers should be selected for the predicted resin curing time so that a proper lay-up can be prepared and the vacuum process carried out before the laminate cures. The manufactured elements require slight machining of the technological surplus, which is difficult to avoid when designing a technically simple form for a single or low- series product.

Keywords: gear housing, hand lay-up composites, vacuum bag, adaptation projects

WYKONANIE OBUDOWY PRZEKŁADNI TECHNIKĄ LAMINOWANIA RĘCZNEGO Z WORKIEM PRÓŻNIOWYM

Przedstawiono eksperymentalną procedurę wykonania jednostkowego wyrobu - obudowy przekładni - techniką laminowania ręcznego z workiem próżniowym, w ramach projektu adaptacyjnego. Zastosowana procedura technologiczna obejmowała wykorzystanie pierwotnego elementu jako modelu do wykonania formy, wykonanie formy oraz wykonanie na niej dwóch elementów z dwóch alternatywnie wzmocnionych laminatów (mata oraz tkanina krzyżowa) metodą kontaktową. Na podstawie obserwacji poczynionych w trakcie prowadzonych czynności technologicznych oraz na podstawie oceny wytworzonych wyrobów stwierdzono m.in., że technika laminowania kontaktowego z użyciem worka próżniowego jest bardzo dobrą i prostą metodą wykonywania wyrobów jednostkowych. Zastosowanie próżni zapobiega występowaniu wad typowych dla laminowania ręcznego, jak delaminacja, zamknięte pęcherze powietrza czy (szczególnie) niedoformowanie w obszarach zakrzywionych o małych promieniach. Stwierdzono też, że oryginalne rozwiązanie polegające na zdejmowaniu z modelu/formy półproduktu w postaci części utwardzonego stosu i kontynuacja laminowania pozostałych warstw poza modelem/formą jest skuteczne, nie ma widocznego wpływu na jakość wyrobu i znacząco ułatwia odformowywanie. Istotną rzeczą przy technice z workiem próżniowym jest odpowiedni dobór ilości utwardzacza do żywicy. Powinien być on poprzedzony pomiarem temperatury pomieszczenia, w którym prowadzi się proces oraz oszacowaniem czasu laminowania kontaktowego danego stosu - należy dobrać ilość warstw do przewidywanego czasu sieciowania żywicy tak, aby zdążyć przygotować i przeprowadzić proces próżniowy przez utwardzeniem laminatu. Wytworzone elementy wymagały przeprowadzenia nieznacznej obróbki mechanicznej naddatków technologicznych, czego trudno uniknąć przy projektowaniu prostej formy dla wyrobu jednostkowego.

Słowa kluczowe: obudowa przekładni, technika laminowania kontaktowego, worek próżniowy, projekty adaptacyjne

INTRODUCTION

The gear housing is an important element as it protects the gear system against the access of atmospheric agents orhuman activity and protects the surroundings of the system against splashing oils and greases. The housing also partially silences the machine's operation [1, 2]. Gear housings are usually made of metallic materials, mainly steel or cast iron, which results from their relatively low price in high volume production, high mechanical strength and durability. However, steel products are heavy and have low corrosion resistance in freshwater and salt water environments as well as in chemical environments. Their use is also limited in systems connected to the electricity grid due to the risk of electric shock. Composite materials allow at least a part of these disadvantages to be minimized or eliminated [3, 4]. The process of redesigning the steel housing construction and replacing the material is called an adaptation project. Its main purpose is to improve a particular feature of the product [5, 6]. Composites are materials that allow product properties to be shaped in an optimal way [7, 8]. Fiber reinforced polymer (FRP) laminates are of the most popular composite materials [9, 3]. When necessary, they enable relatively simple and cheap production of single or low-series products and do not require the use of complicated devices in the production process [3, 10]. Their main limitation is the ability to work at elevated temperatures [11, 12], but for most typical gears, the operating temperature does not exceed the range of applicability of typical hardened resins. The hand lay-up technique, the most suitable for single or small-scale production, consists in saturation of the chopped-strand mat or fabric layers with the liquid polymer resin (matrix material). Polyester resins or epoxy resins are most frequently used. Curing of the resin may take place at room temperature. Products manufactured by hand lay-up lamination may have drawbacks, however, the technique allows some problems characteristic for pressure-assisted methods to be avoided, for example gelcoat application [13, 14]. The quality of the final product made by the hand lay-up method depends mainly on the materials used and the experience of the manufacturer. The most common disadvantages are an insufficient reinforcement volume fraction and air bubbles closed in the material [15,16]. The number of defects can be minimized by using a flexible vacuum bag. The non-cured prefinished product is placed inside a bag connected to a vacuum pump and compressed by the bag after the air is removed from it. The excess resin is removed from the preform and the preform is pressed against the mold, which ensures that the correct angles, shapes and dimensions of the manufactured product are maintained, according to the design.

The article presents an experimental procedure for the adaptation and production of a single product - a gear housing. The hand lay-up laminating technique extended by using a vacuum bag was applied. The aim of the work is to evaluate the effectiveness of works undertaken as a universal procedure for the production of composite elements in the frame of an adaptation project.

TECHNOLOGICAL PROCEDURE

The assumption of the technological procedure was to use the original element as a model to produce the mold, with subsequent reproduction of this element from a particular type of laminate using the hand lay-up method. Two housings were made - one reinforced with chaotic fibers arranged in a plane (chopped-strand mat), the other with cross-arranged ones (plain weave fabric). Vibroacoustic testing, aimed at determining the applicability of polymer composites in machine building is planned to be carried out on the composite housings [10, 17]. These tests will be the subject of separate future studies.

The steel housing, supplied by the customer, was a model for the mold and finally - for the composite product. The product is to preserve the shape, angles and dimensions. At the first stage of the works it was necessary to properly prepare the model to ensure adequate taper of the mold and to prevent the occurrence of any negative angles. The metal housing was over-built for this purpose in some (appropriate) places using technical plasticine (Fig. 1a). It does not damage the steel casing - after the mold is made it can be removed. After the model was treated with the plasticine, cut aluminum foil sheets were stuck to its surface (Fig. 1b).

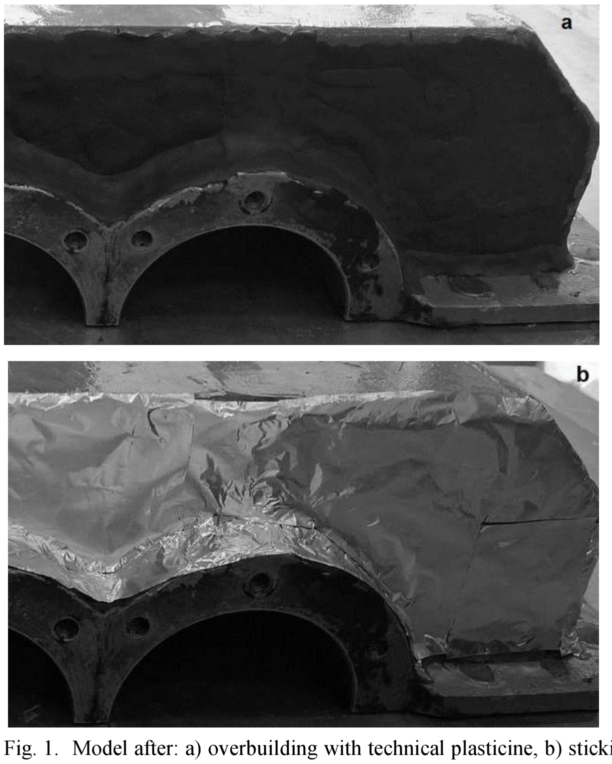

Fig. 1. Model after: a) overbuilding with technical plasticine, b) sticking aluminum foil

Rys. 1. Model po: a) wypełnieniu plasteliną techniczną, b) nałożeniu folii aluminiowej

The foil protects the technical plasticine against direct action of the polyester resin components, leading to adverse effects changing the surface of the plasticine (dissolution, swelling). Then a layer of release agent (wax paste TR-104) was applied to the model surface - aluminum foil.

After applying the release layer on the model, the process of laminating the shell mold was started. To create the outer (working) layer, vinyl ester gelcoat 60014 by HAVEL COMPOSITES and Butanox M 50 initiator were used. The gelcoat was applied with a flat brush so that the thickness of the layer was less than 1 mm. The wet layer did not have visible porosity, wrinkles or holes. Before applying the construction layers, the gelcoat layer was brought to the initial curing state ("hard rubber"). The next stage of works included applying appropriately cut glass matting sheets (Krosglass, 540 g/m^2) to the surface of the gelcoat layer and impregnating them with the polyester resin, catalysed as shown in Table 1.

TABLE 1. **Composition of used polyester resin**
TABELA 1. **Receptura użytej żywicy poliestrowej**

Ingredient	Amount [g]
Polyester resin ESTROMAL 14 LM – 01	150
Catalyst METOX 50	2.25

After applying four layers, the mats were left to cure. Applying more layers at this stage would lead to high stiffness of the structure, which would make the process of separating it from the model difficult. Therefore, a decision was made to remove the hardened intermediate product consisting of the gelcoat layer and four construction layers from the model, with subsequent complementary lamination - the total number of mat layers is twelve. It should be emphasized that this approach is original and allows one of the basic problems occurring in the production of laminated single products as part of adaptation projects to be overcome, which is releasing the product from the mold.

Slight defects occurred on the surface of the hardened mold - local wrinkles of the gel coat layer, adhesion of aluminum foil fragments (Fig. 2).

Fig. 2. Intermediate product mold - defects on gel coat surface
Rys. 2. Półprodukt formy - uszkodzenia na powierzchni żelkotu

Removing defects is easy, requiring only grinding the surface using fine-grained abrasive papers, while the edges of the molds containing larger technological surpluses were ground off with a file. The resulting cavities were filled with a specially prepared paste composed of polyester resin and colloidal silica. After curing the paste, the mold surface was again smoothed with abrasive papers.

The main stage of technological work was producing the gear housings made of polymer-fiber composite on the previously created form. They were made on the basis of two alternative glass reinforcements - cross (plain-woven) fabric and chopped-strand mat. A KROSGLASS glass mat with the areal mass of 540 g/m^2 and a KROSGLASS fabric with the areal mass of 300 g/m^2 were used.

The reinforcement materials were cut into sheets according to previously prepared templates. This approach ensures that the fibers are arranged in layers in accordance with the design assumptions that were made, guaranteeing the required stiffness of the product. After preparing the resin in accordance with Table 1, hand lay-up lamination was started using brushes and rollers. In the case of the mat, two layers were applied to the form, in the case of the fabric - 6 layers. The non-cured stack was compressed using a vacuum bag. A package consisting of a delamination fabric, a dividing film, and an absorbent fabric was placed under the bag for this purpose. The vacuum inside the package was maintained until the resin was fully cured. The diagram of the connection of the vacuum package to the vacuum pump is shown in Figure 3.

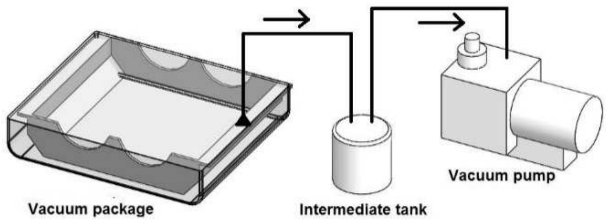

Fig. 3. Diagram of connecting vacuum package to pump
Rys. 3. Schemat podłączenia pakietu próżniowego do pompy

After the process was completed, the bag and the additional layers were removed, the intermediate product was removed from the mold and the further (complementary) lamination process was carried out outside it. This is a similar approach used to make the mold making. In the case of the mat-reinforced product, 7 layers were additionally applied (in the sequence: 3 mat layers - vacuum bag process - 4 mat layers - vacuum bag process), while in the case of the fabric-reinforced product there was an additional 18 layers (in the analogous sequence 6-6-6). The ratio of the amount of catalyst to the amount of resin and the ambient temperature were precisely determined in order to set the time required for curing the resin. The lamination process was carried out at a temperature of 18÷20°C, and the time to start curing the resin was planned for 45 minutes. The time was determined from the moment the resin and hardener are mixed together, until the vacuum pump is switched on and vacuum is obtained in the bag. During this time, all the stages related to lamination should be performed: layering of the mat/fabric layers and impregnation with resin, applying the additional layers for the vacuum-bag process, closing the bag, connecting the bag valve to the vacuum pump system, and opening the valves. Similar to the case of processing the mold, the intermediate housings were subjected to further complementary lamination and finished using a vacuum bag. After the laminating process, the products had surpluses at the edges, which were mechanically removed using a circular saw and a hand-file.

EVALUATION OF MANUFACTURED ELEMENT

Images of the produced and finished composite housings are shown in Figure 4.

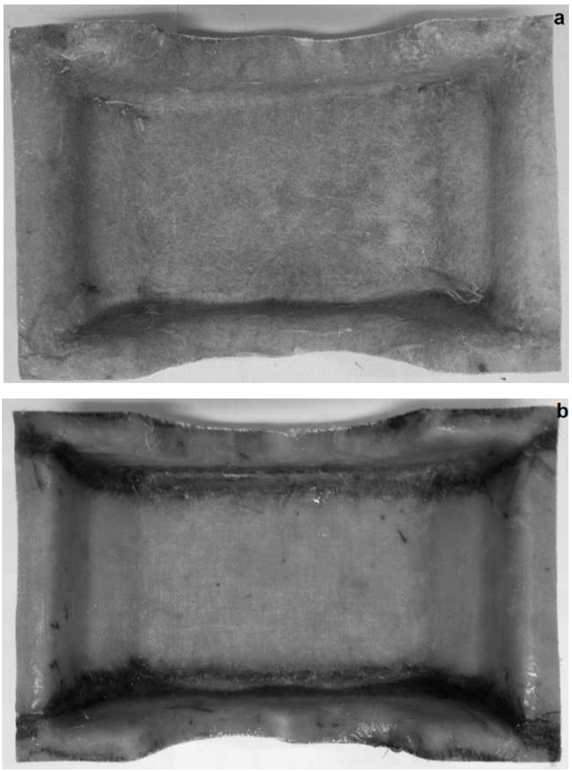

Fig. 4. Final product (gear housing) made of: a) glass chopped-strand mat, b) glass plain-woven fabric

Rys. 4. Finalny wyrób (obudowa przekładni) wykonany z: a) maty szklanej, b) tkaniny szklanej

The number of glass mat layers in the product is 9, while the number of fabric layers is 24. The differences in the quantity result from the different basis weights of these reinforcements and design requirements in terms of product thickness.

Applying the hand lay-up lamination technique using additional flexible vacuum bag compression allowed typical defects arising in the classic hand lay-up laminating process to be avoided. In particular, they are defects arising near low-radius curvatures in the product - in the case of typical lamination there is often a lack of tightening the impregnated reinforcement to the mold, caused by the elasticity of glass fiber reinforcement and its "springing" from the surface of the mold. The finished products have an even wall thickness, very well-formed shapes, dimensions and angles. There were no delaminations or closed air bubbles inside the product. It was found that the individual mat/fabric layers adhere closely to each other. No deformation was observed due to shrinkage, which is quite often a problem in composite products, especially those with a complicated shape [8]. Undoubtedly, a beneficial effect of avoiding the negative effects of shrinkage comes from the original concept of gradual lamination and curing of several layers of the stack with complementary addition of the subsequent layers.

CONCLUSIONS

On the basis of observations made during the technological works and based on evaluation of the manufactured products, the following conclusions have been drawn:

- The steel gear housing is a model that needs to be properly overbuilt to form a shell mold on its surface. The overbuilding consists in removing openings and depressions.
- The gelcoat layer ensures adequate durability of the mold, guarantees relatively aesthetic product surfaces and facilitates removal of the product from the mold after the process has been completed.
- The hand lay-up lamination technique with additional use of a vacuum bag prevents the occurrence of defects typical of classic hand lay-up lamination: delaminations, closed air bubbles, and lack of adhesion in low-radius curved areas.
- The original solution consisting in removing the semi-finished (intermediate) product, in the form of a hardened stack, from the model/mold and continuing lamination of the remaining layers outside the model/mold is effective. The procedure has no visible impact on the quality of the product and significantly facilitates the process, especially releasing product from the model/mold.
- Selection of the amount of hardener should be preceded by measurement of the room temperature at which the process is carried out and by estimating the time necessary for the lamination process.
- Single or low-series products usually require slight mechanical machining of the technological surplus - designing a complicated mold that enabled avoiding surpluses would involve too large additional costs and would be unprofitable in the case of low-volume production.

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