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Application of Polymer Matrix Composite Materials for the Tractor Safety Frames

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Abstract: Safety frames (Roll Over Protective Structures (ROPS)) are used to provide protection for the tractor operators against being overturned. Main duty of these frames is to protect the tractor during the probable overturns. Up to this time metallic materials have been used for the safety frames. When working conditions and safety criteria are considered, tractor safety frames need high strength, high rigidity, high fatigue strength, high wear resistance and low weight. When these circumstances are considered, we need new generation materials and within these materials polymer matrix composites are the most suitable choice. The objective of this study is to use polymer matrix composites instead of the generally used steels for the tractor safety frames in order to obtain higher strength and longer life. Also in the logistics point of view it is possible to produce modular structures by using these composite materials and this will give the chance to transport higher amount of products in the same volume in the international transportation. Thermoset epoxy was selected as matrix material due to its high strength, low shrinkage ratio, suitable cost and suitable high temperature properties. Glass fibers were selected as the reinforcement materials in the study. Resin transfer molding (RTM) method was selected for the production of the composites when the geometry of the designed safety frames, desired mechanical properties and raw material costs were considered.
Key words: Safety frame, polymer matrix composite, tractor, roll over protective structures (ROPS)

INTRODUCTION

The purpose of this study is to develop a lighter, more durable, less corrosive and long-lasting Roll Over Protection Structure(ROPS) with dispatched disassembled to be installed on desired location ability; instead of welded steel safety frames, which are currently in use to reduce the risk of mortality and physical injuries occurred during the operation of tractors.

ROPS, which are used to provide safety for operators of the tractors that widely used in agriculture, are generally produced from metal materials via welding processes. However, due to following needs that we revealed, in this study we intended to use alternative materials to manufacture ROPS.

- Corrosion resistance
- Lighter and lower volume
- High Durability
- Easy Installation
- Lower number of Manufacturing errors
- Increasing market share with new innovative products

There is limited number of studies on manufacturing safety frames from alternative materials. (Etherton et., 2007) And it is observed that these studies did not transform in to stable commercial products, and they stayed as scientific researches.

According to studies performed all around the world by many different organizations in several countries, during the operation of industrial and agricultural tractors, majority of accidents, which are resulted in loss of life and severe injuries, are related to rollover of tractors (Springfeldt, 1986).

Composites as a new innovative material categorized as plastic, metal or ceramic matrix composites according to material used in its matrix (Şahin, 2000). On this study, it is intended to manufacture safety frames with composite materials instead of generally used metal materials. And it is evaluated that best suitable material would be polymer matrix composites, to satisfy the expectations for the safety frames.

Polymer matrix composites are the one of the best possible options for intended applications due to their high durability, fracture toughness and abrasion resistance properties (Kayrak, 1999).

For the structural analysis made during this study, computer aided study of Görüryılmaz(2011) on safety frames made of metal materials, is reviewed to gain inside about the path will be taken to advance the study.

The prototype of tractor safety frame manufactured is manufactured in accordance to Turkish regulation on ROPS as "Tekerlekli Tarım veya Orman Traktörlerinin Devrilmeye Karsı Koruma Çerçevesi ile İlgili Tip Onay Yönetmeliği (79/622/AT)". And according to regulation above, the level of sufficient durability to protect the safety of operator is designated. On this reason, it is aimed that the manufactured safety frame will protect the operator who is located in the safety protection area, on roll over or similar accidents.

MATERIALS and METHODS

In this study, to specify visible or operational properties of purposed safety frames and to provide accordance to local and international legislations, Turkish regulation on ROPS as "Tekerlekli Tarım veya Orman Traktörlerinin Devrilmeye Karsı Koruma Çerçevesi ile İlgili Tip Onay Yönetmeliği (79/622/AT)" is referred.

Method purposed in this study, is analyzed deeply to provide accordance to legislations and needs analysis for the production of safety frames made of composite material and its production processes, is structured as a result of these analyses. And conceptual design is realized considering results of needs analysis.

On this phase of study, it is decided to carry out "developing alternative designs" and "specifying materials and production processes" tasks simultaneously. The main reasons for decision are to be able to deal all factors on design and materials as a whole and to analyze correlation between producibility and functionality.

Considering the need analyses, many different variations of safety frame designs are studied. And out of these studies, two designs are selected according to their eligibility to fit for purpose and ability to be subject to functional and cost analyses.

In alternative design development phase, finite element analysis carried out in ANSYS software, for the structural evaluation the developed models. And a research made on various reinforcement and matrix materials for the composite safety frame according to results.

Carbon fibers are evaluated as a suitable reinforcement material for the production of a durable and light tractor safety frames, due to their high durability, light density and high rigidness properties.
However, its high unit meter square cost, less importance on lightness in product according to need analysis, prevents carbon fiber being a suitable reinforcement material for this study. So, as a result, after evaluation, fiber glass comes up as a more suitable reinforcement material for this study. As, it is projected that with their unit densities, high durabilities, and advanced elastic properties according to carbon fibers, fiber glass reinforcements would make a positive effect on lowering cost, easing production process and characterization of parts, fiber glass is selected for the reinforcement material on this study. On this scope of research One-direction weave type fiber glass fabrics are evaluated and among those fabrics coupon samples are prepared and tested individually for tension and shear according to D3039 and D3518 standards in various fiber volume. And all these tests are carried out in the labs of Material Science and Engineering department of Anadolu University (Mihaliç, 2013).

On the researches in this study, unit part sensitivity and processes for safety frame tests applied from vertical and horizontal directions are reviewed and according to results of these processes, usage epoxy resin as the matrix of composite material is decided. And also properties of epoxy resin, like high durability, lower draw ratio, high temperature endurance, ability to set the time of process according to size of fabric, effected on the selection of epoxy resin as most suitable the matrix material.

Resin transfer molding(RTM), "Out-of-Autoclave" Prepregs (OOA-Prepreg) production methods and pultrusion methods are evaluated during this research and due to parameters like, better unit production time, lower raw-material costs, lower first setup costs, better raw material shelf life, better supply lines, applicability of reinforcement materials, ability of setting up fiber volume and ensuring high dimensional sensitivity, ability of arranging fiber directions on operation, RTM method is selected as the production method.

RESULTS and DISCUSSION

Design and Analysis

Need analysis prepared for this study can be seen on Table 1 and Conceptional Design created in accordance to need analysis can be seen in Figure 1.

Figure 1. Conceptual design

Developing alternative designs

The main points that paid attention on the developing of alternative designs can be listed as below;

- Accordance to different production methods and material selections.
- Ability to gain more durable structure as a result of analysis will made forthcoming phases.
- Responsive design to allow changes on wall thickness in possible required areas.

Table 1. Need analysis

S/N	Requirement Definition	Course of action	Application according to requirement
1	Due to low volume and weight, it is possible to transport higher amount of product in the international transport	Production of low density and high strength dissassembled product which can be easily installed by the user in the desired location	Design and production of three pieced safety frames which are supported by the usage of inserts, have no welded structures and with reduced weight
2	Production of ROPS which can be easily installed by the user after transportation	Production of ROPS suitable to insert usage by the use of alternative materials	Beside the design improvement which is suitable to the insert usage, creation of industrial and structural alternative designs that are enable to produce with alternative materials
3	Production of lower cost ROPS by removal of welding and trimming costs	ROPS production which is supported by fasteners	Beside the design improvement which is suitable to the insert usage, creation of industrial and structural alternative designs that are enable to produce with alternative materials
4	Cost reduction by the removal of dying process costs and production of ROPS with high corrosion resistance and longer lifetime	Material usage without KTL and dying process	Alternative material selection which is applicable to ROPS production and without dying process
5	Cost minimization of new product	New generation material selection for ROPS with the similar security advantages with traditional materials.	Providing of ideal raw material usage according to optimum design requirements and determination of suitable materials
6	Production of new product which is suitable to "Tekerlekli Tarım veya Orman Traktörlerinin Devrilmeye Karsı Koruma Çerçevesi ile İlgili Tip Onay Yönetmeliği" (79/622/AT)	Creation of design according to 79/622/AT requirements	Realizing of industrial and structural designs according to 79/622/AT requirements and especially ROPS security area
7	Design of feasible and easily molded ROPS which is usable for new material usage	Determination of external form of ROPS which can be buckled according to sandwich structured design	Control of suitability of sandwich structure by using finite element analysis method, by the improvement of at least two different conceptual designs
8	Production of new product with safety criteria according to "Tekerlekli Tarım veya Orman Traktörlerinin Devrilmeye Karsı Koruma Çerçevesi ile İlgili Tip Onay Yönetmeliği"	Simulation of suitability of computer aided designs to 79/622/AT with finite element analysis method	Realizing static analyses with ANSYS structural module quickly and with lower error probability according to 79/622/AT requirements
9	Longer lifetime materials build on corrosion resistance	Realizing of lifetime test of alternative materials	Material usage based on certified test specs
10	Taking the "Tekerlekli Tarım veya Orman Traktörlerinin Devrilmeye Karsı Koruma Çerçevesi ile İlgili Tip Onay Yönetmeliği" (79/622/AT) certification and validation procedure	Execution of real physical test at the certified institution	Making preparation according to 79/622/AT and completion of validation procedures before the execution of real physical test

Two design alternatives are developed in line with these points. First of these design alternatives is a safety frame structure consisted of two assembled "C" shaped profiles. On this design purpose of outer profiles are create structure to provide resistance to all loads would be created. And other profiles are will be only used to provide cover and create a cap. The main purpose of using shell form and cap attached to it is; allowing possibility of installation of electric and other transfer cables in the safety frame, reach and respond them when needed by dismantling the cap.

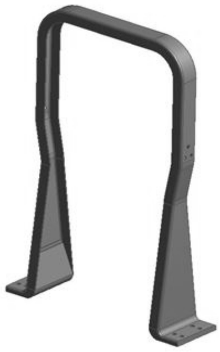

Figure 2. Alternative design 1 (Capped structure)

A perspective drawing of capped alternative design can be seen in Figure 2. On this drawing, to give a better view of the load carrier "C" profile shell and to make the details of this design comprehensible, cap design is removed on purpose, and shell structure is shown solely.

Second design alternative (Fig.3) is the filled structure design which can be predicted as more prone to composite production and would have better results in forthcoming pre-structural analysis.

In contradiction to previous design, on this alternative design, structure designed as monolithic because composite layers are produced as wrapping around, usually foam structured, inner core material. On this reason, acquired sandwich structure is widely used and preferred and expected to achieve targeted durable form more easily. And also it is predicted that second alternative design would cost less according to production method.

On second design, as it is filled unlike first one, cable installment cannot be placed in Safety frame. At first look it seemed like a disadvantage or a deficiency. However, if second design is proved to be more advantageous in durability and cost efficiency, this deficiency about installing cables can be ignored.

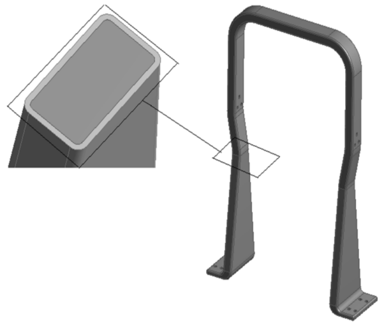

Figure 3. Alternative design 2 (Filled structure)

Structural analyses of two alternative designs can be seen below. (Fig.4, Fig. 5)

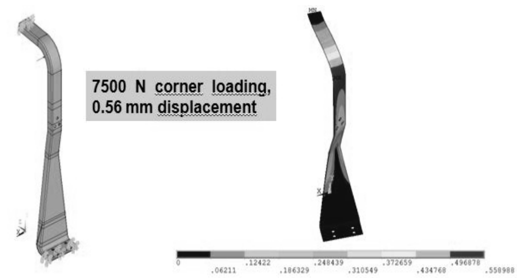

Figure 4. Analysis of alternative design 1 (Capped structure)

Figure 5. Analysis of alternative design 2 (Filled structure)

According to results of analyses, displacement values of second (filled) design proven to be lower than first (capped) design. If the results are evaluated with regard to results of analyses and producibility, second design is expected to be produced more easily, and based on this, production of filled one will be cost lesser then first one.

Materials Selection and Production Method

The results of tension and shear test, which are used to select suitable reinforcement material for the study, can be seen in Fig. 6 and Fig. 7

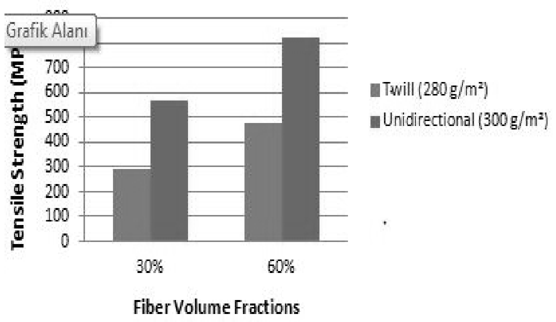

Figure 6. Results of tensile tests

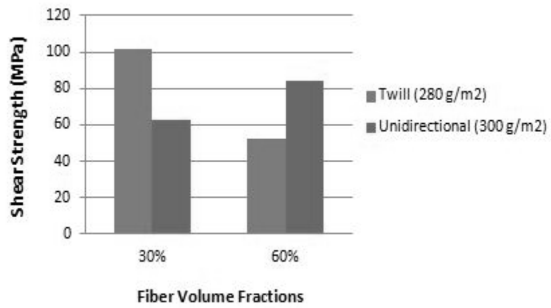

Figure 7. Results of shear tests

According to these results the composite material combination that demonstrates the highest strength is unidirectional reinforcement with 60% fiber volume fraction. However, ROPS (Rollover Protective Structure) needs to resist both tension and compression load, so Twill reinforcement was chosen in this study as reinforcement material

The scoring matrix table, used for selecting the suitable production method can be seen in Table 2 below.

As can be seen in Table 2, RTM method is decided as most suitable production method according to parameters like Production of complex shaped parts, raw material cost, raw material lifetime, dimensional precision.

Table 2. Production methods scoring matrix

	PRODUCTION METHODS		
CRITERIA	**RTM**	**Pultrusion**	**OOA Autoclave**
Raw Material Costs	3	4	2
Production Costs	3	4	2
Investment Costs	2	1	4
Raw Material Lifetime	5	5	2
Process Easiness	4	3	5
Production Rate	4	5	3
Production of Complex Shapes	5	2	3
Fiber Volume Ratio	4	2	5
Dimensional Presicion	5	3	4
Mechanical Strength	4	3	5
Total	**39**	**32**	**35**

CONCLUSIONS

The outcome of this study will be produced as a prototype to test the results of study in real life. As an alternative material to produce composites have more specific production methods then metal materials, so, this study is based on two main structural designs, "C" shaped Capped Shell design and Filled structure design. According to results analyses made, Filled structure design is selected to be implemented.

Composite production methods are evaluated, with respect to producibility of two possible safety frame designs, and according to evaluation results are gathered in production method scoring matrix, RTM comes to the forefront as most suitable production method.

Due to their unit densities, high durabilities, advanced elastic properties according to carbon fibers and simple procurement procedures, Fiber glass is selected as reinforcement material. Whether in the production of the prototype, outcome of this study, or in the phase of mass production, it is determined that fiber glass reinforcement material would lower the unit section costs and positively effect to the targeted properties of the end product like durability or high fatigue strength.

During this study, unit part sensitivity and processes for safety frame tests applied from vertical and horizontal directions are reviewed and according to results of these processes, usage epoxy resin as the matrix of composite material is decided. And also properties of epoxy resin, like high durability, lower draw ratio, high temperature endurance (Tg), ability to set the time of process according to size of fabric, effected on the selection of epoxy resin as most suitable the matrix material.

This study consist of selection of material and production method and developing suitable design for the tractor safety frame, intended to produced by using next generation of innovative materials. As an extend of this study's outcomes, in following studies it is aimed to develop and prototype a full safety cabin design which is made of polymer matrix materials.

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