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APPLICATION OF LAMINATE IN MOBILE WORKING MACHINE CABS DESIGN

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Abstract:
Design of mobile working machine cabs is unchanged for years. First used cabs were non-structural in combination with safety frame around it. Newer designs are "self-protective", where the safety construction is integrated within main frame of the cab whereas conventional mechanical engineering materials are used in their production. These materials are weldable steels with sufficient strength to meet cab safety standard requirements, coated with paint to protect cab body from corrosion and to give recognition character to the machine. This concept is widely used until now. The paper deals with usage of non-conventional materials in cab building in terms of mechanical and safety-, applicable-, utility-production-, economical- and ecological-properties, and to compare it with conventional design.
Keywords:
Mobile working machine Cab, Laminate Cab, ROPS and FOPS tests

1. INTRODUCTION

For mobile working machines (MWM) is important their power, or quality and effective running, but at last time after death accidents is still more important their safety. The most of machine accidents were roll-over´s. Machines 60 years ago were without cabs or any chassis over the operator. But the requirements on safety obligated machine designers to design some chassis for safety. It is called FOPS and ROPS. FOPS are falling object protective structures while ROPS roll over protective structures. For protection opposite atmospheric exposure designers have made whole cab with FOPS/ROPS. Some cabs have got extra FOPS/ROPS chassis. But they are used on forest machinery. The development of cabs today continues mostly by material progress. Almost every year arise new modification of material or whole new material. New trends of material progress come to synthetic materials, composites especially. For cabs are considerable polymer composites – laminates. So the development focuses to laminate cabs. We develop new earthmoving machine whole-laminate cab now, applied at HON 200 wheel loader being developed at PPS Group Detva (Slovakia) company in cooperation with STU´s Faculty of Mechanical Engineering in Bratislava (Slovakia).

2. PROJECT OF CONVENTIONAL-MATERIAL (STEEL) CAB

PPS Group j.s.c. Detva in collaboration with STU Bratislava, is currently preparing the re-launch of the successful hydraulic rotary loader and manipulator DETVAN – HON in two size categories 150 and 200 (Fig.1, Fig.2). The loader cab is equipped in a practical and convenient way to make the operator's work easier.

Figure 1. DETVAN HON 200 loader prototype

Figure 2. DETVAN HON 200 telescopic manipulator prototype

Current cabin metal design is made of thin-walled steel beams and steel plates. The 3D cab model is presented at Fig.3 and its real representation is shown on the Fig. 4 and Fig.5.

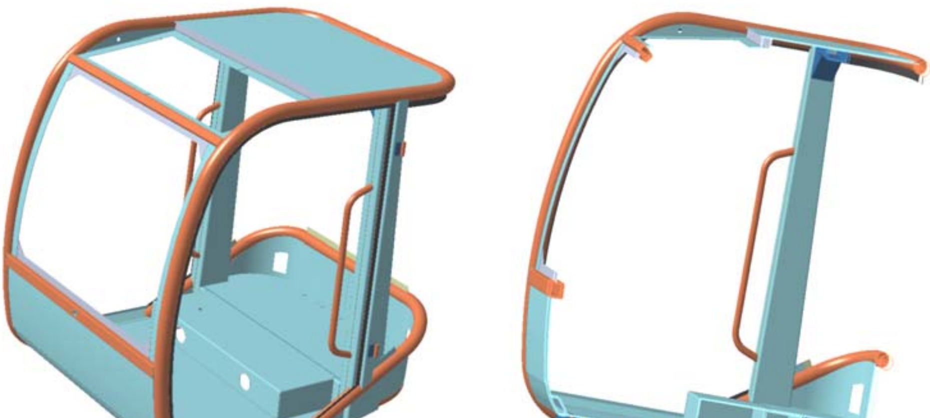
Figure 3. Shape virtual design of MWM metal cabin

Figure 4. Metal cab body-in-white prototype

Figure 5. Metal cab final prototype

3. PRELIMINARY DESIGN OF NON-METAL CABIN

The composite material cabin is to be designed in accordance with this metal cabin project. Composite cabin design presented at Fig.6 and Fig.8 was subjected to FEM computational structural analyze and modifications to meet both shape and strength security requests. While unconventional cabin project is at its beginning, material considerations take main part at this time.

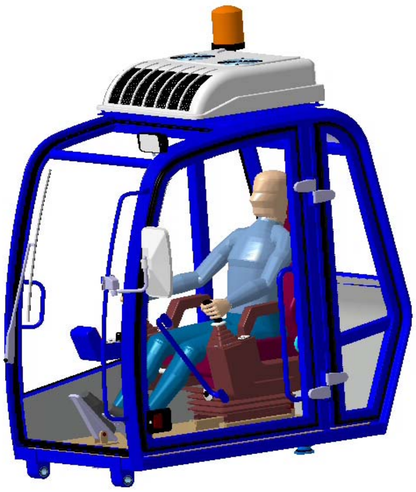

Figure 6. Laminate cab model

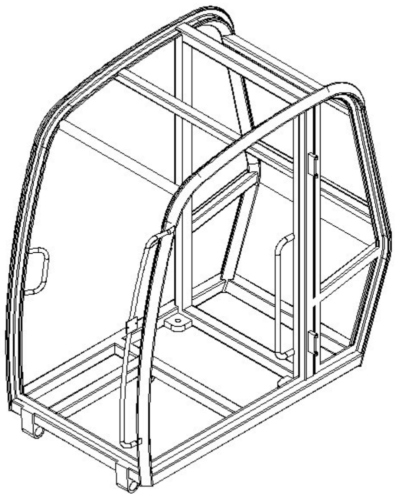

Figure 7. Laminate cab body in white model

Table 1: Properties of glass laminate constituents

MATERIAL	CLASS		RELATIVE WEIGHT	ELASTIC TENSILE MODULUS	TENSILE STRENGTH	RELATIVE TENSILE FAILURE ELONGATION	COEFFICIENT OF THERMAL EXPANSION	THERMAL CONDUCTIVITY
			$kg \cdot m^{-3}$	GPa	MPa	%	$\cdot 10^{-6}$ $m \cdot (m \cdot K)^{-1}$	$W \cdot (m \cdot K)^{-1}$
Epoxy	Polymer	Reacto-plastics	1100 - 1800	1,0 - 6,0	35 - 100	1,0 - 6,0	60	0,1
PolyEster			1200 - 1500	2,0 - 4,5	40 - 90	2	100 - 200	0,2
Glass fiber	Fiber	E	2 600	70	2 000	4,5 – 4,9	5,0	0,90
		v-R_m	2 500	83	4 200	5,4 – 5,8	4,1	0,90

Composite materials have unprecedented mechanical and physical properties, which can be tailored to meet requirements of particular application. For the first project approximation is reflected one of the oldest and best known composite materials – fiberglass.

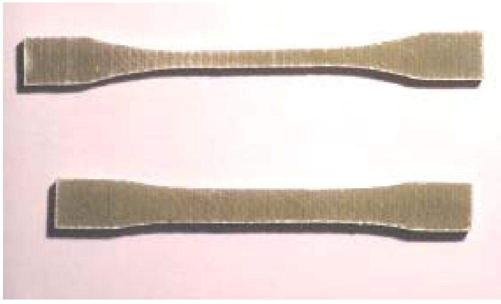

Figure 8: Multiaxial composite specimen

The most important mechanical and physical properties of polymer reinforced with glass fiber, composite constituents are shown in Tab.1.

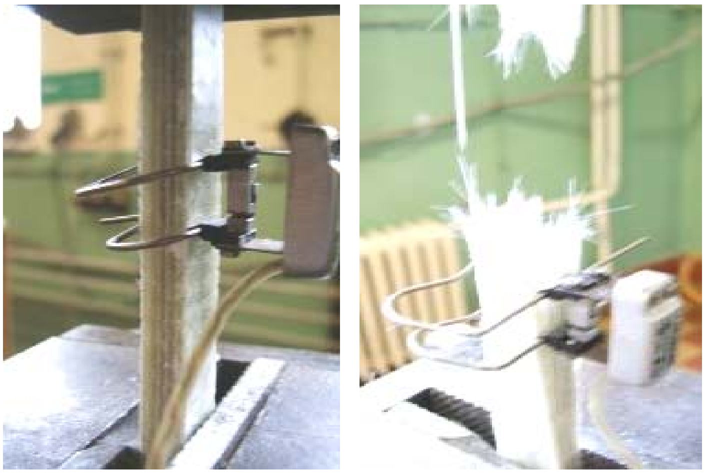

Figure 9: Multiaxial composite specimen testing

The most efficient composite reinforcement form is continuous fibers. Because of the low transverse strengths of unidirectional laminates, they are rarely used in structural applications. Laminates with layers in several directions (quasi-isotropic) are used up to the present in general purposes to meet requirements for strength, stiffness, buckling and so on. For the laminate design of cab strength characteristics of laminate profiles were estimated by experimental way at solution department laboratories (Fig.8-Fig.9). Partial result of this project was design and proposition of optimized profile (for subject function of maximum load capacity) parameters, which should be compared with non-optimized cab structural profile and used to build up of alternative cab. Results of these tests (Fig.10) approve, that accordingly chosen laminate (especially unidirectional one) has comparative strength properties as Steel DIN 37. In addition, this material has very good shape memory, even under high stress does not show any plastic deformation. However, this means that such structure has not deformation energy absorption ability by irreversible manner, under external loads. In spite of legislative demands, this relative limitation should not be disadvantage for MWM cabs, because irreversible absorption of deformation energy is necessary under dynamic loads (for example impact or hit at high speed), which does not occur at MWM´s.

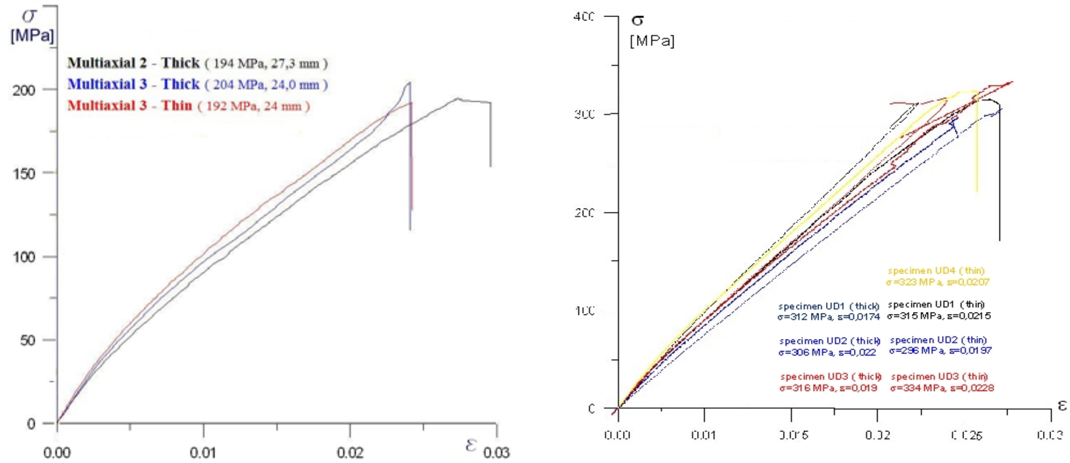

Figure 10: Multiaxial (left) and unidirectional (right) laminate stress-strain curves

For comparative and production reasons, there were done structural analyses of metal and laminate cabins at FEM solving tool COSMOS and ANSYS.

4. COMPUTER FEM SIMULATIONS OF SAFETY TESTS

Inputs:

ROPS test was simulated by loading:

1. Vertical – downward
2. Horizontal – lateral
3. Horizontal – longitudinal

For MWM´s of mass category m ε <700; 10 000> kg, standard structural test of cab requires loading cab structure under:

1. Vertical-downward loading, by 19,61 multiple of machine mass
2. Horizontal-lateral loading, by 6 multiple of machine mass
3. Horizontal-longitudinal loading, by 4,8 multiple of machine mass

Cab is applied at DETVAN HON 200 loader, with approximate overall weight m=4 000 kg. Testing loads are presented in tab.2:

Table 2 : ROPS test cab forces

Testing direction	Testing load	Standard load	Testing force F (N)
Vertical	downward	$F = 19{,}61 \cdot m \cdot g$	78 440
Horizontal	lateral	$F = 6 \cdot m \cdot g$	24 000
	longitudinal	$F = 4{,}8 \cdot m \cdot g$	19 240

As materials were chosen :

1. Isotropic material - Steel type – simulating current used cab structure material
2. Unisotropic material – Multiaxial composite type – simulating preliminary composite cab design with
   a. Non-optimized profile
   b. Optimized profile

Outputs

VonMises normal stresses and deformations were computed by COSMOS software FEM algorithm for all material and loading combinations of considered cab. Numerical results of FEM computation are summarized in Tab.3 and Tab.4.

Graphical FEM analysis outputs are iso-areas of normal stresses respectively deformations. Maximum normal stresses are obtained in multiaxial non-optimized profile composite, stressed by horizontal longitudinal loading, while maximum deformations are observed in multiaxial optimized profile, stressed by horizontal lateral loading. Both most inconvenient material-loading combinations are presented at Fig.11 and Fig.12.

Table 3: Maximal normal stresses and deformations for FEM analysis of ROPS cab tests

Load		Testing force	Material			
			Anisotropic multiaxial laminate			
			Non-Optimized profile		Optimized profile	
position	direction		Maximal normal stress	Maximal deformation	Maximal normal stress	Maximal deformation
		F_t	σ_{max}	δ_{max}	σ_{max}	δ_{max}
		N	MPa	mm	MPa	mm
Vertical	downward	78 440	86	9,5	71	9,9
Horizontal	lateral	24 000	158	68,0	130	72,0
	longitudinal	19 240	166	13,1	162	14,0

Table 4: Maximal normal stresses and deformations for FEM analysis of ROPS cab tests

Load		Testing force	Material	
			Isotropic steel	
position	direction		Maximal normal stress	Maximal deformation
		F_t	σ_{max}	δ_{max}
		N	*MPa*	*mm*
Vertical	downward	78 440	86	0,5
Horizontal	lateral	24 000	158	3,9
	longitudinal	19 240	163	0,7

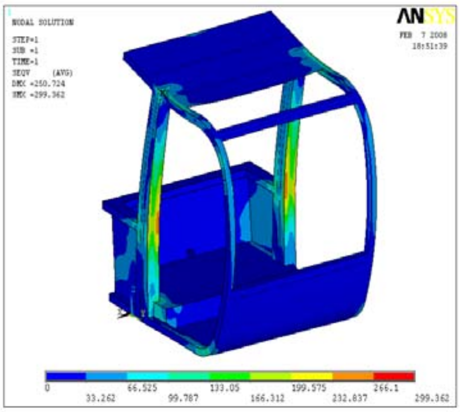

Figure 11: Normal stress (Pa)-multiaxial non-optimized laminate profile (horizontal longitudinal loading)

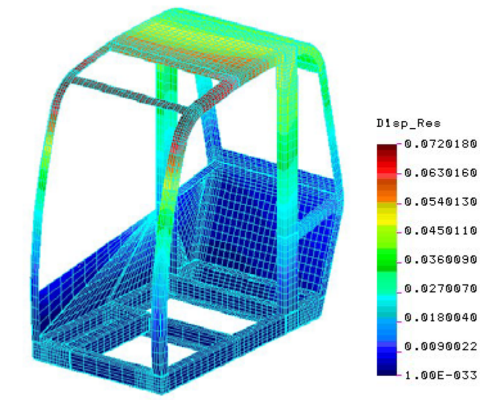

Figure 11: Deformations (m)-multiaxial optimized laminate profile (horizontal lateral loading)

5. CONCLUSION

By comparison of results we can observe that normal stresses are not considerably material dependent (what was expected), however it is apparent that deformations are markedly material dependent. This behavior is due to great difference between elastic modulus of steel and multiaxial composite. We can state of received results, that multiaxial-composite cab match to maximum deformation, since they do not interfere into the deformation limiting space. We can see from tabled composite cab results that optimized profile cab maximum normal stresses are about 3 – 18% lower, than those at non-optimized profile cabin, even though deformations are slightly higher. Hence we can advise using of optimized profiles. While interpreting of FEM results it must be considered, that computation does not respect machine frame deformation or clearances in cabin seating, as well success of real cabin test results depends on its final design and its individual parts manufacturing quality. Significant result of laminate cab design is also the mass reduction. In this concrete case it possible to reduce the cab mass more then about 20% to the steel cab design.

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