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Research paper

"Pickup" Car Type Frame Elements Study Performance, which are Made of Composite Materials

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Abstract

The cars frame structures advantages and disadvantages analysis is carried out. The car metal capacity reducing ways while simultaneously providing the rigid and strength characteristics of the frame are determined. It is proposed to use 3D-printing from the composite materials offered in this article when repairing the frame or when manufacturing new parts for automotive industry. The analytical studies of the stresses and displacements of the frame, made from the proposed composite materials, have been carried out.

Keywords: *analysis, car frame, composite materials, displacement, 3D modeling, stress*

1. Introduction

1.1. Overview

Contemporary automotive industry includes many types of car bodies, a large percentage of which are pick-up trucks. They are quite widespread, because they combine a comfortable car and a small truck.
One of the most commonly used pickups in Ukraine is the Mitsubishi L-200.

Fig. 1: Mitsubishi L200 car

The fact that the car is widely known does not relieve it of its shortcomings. One of these drawbacks is the problem with the car frame, which, due to corrosion, improper operation of the car, violation of the technology of manufacturing a frame at the manufacturer's factory, engineering failures, etc., loses its ability to operate and prevents further use of the vehicle for its intended purpose without serious and costly repair of the car's part of the car.
The most common cause of the frame failure is its corrosion, because the body adjacent cargo part location to the passenger due to engineering failures gets atmospheric moisture. During the movement from behind the wheels on the frame fall reagents, this sprinkled in the winter road, which in turn is very corrosive, because they include sodium chloride, calcium chloride and magnesium chloride.

1.2. Relevance

The running gear serves to ensure the direct interaction of the car with the road surface. It consists of a frame, a wheel propeller, suspension brackets and bridges [1].
The frame is the car's backbone. It is intended for installation and mounting of the engine, transmission units, chassis, additional and special equipment, control mechanisms, as well as cabs and bodywork.
The history of the frame chassis is rooted up to the very beginning of automotive development. Constructors of cars borrowed this idea in rail transport. The first frames were made of solid wood [2]. In addition, the material for frames in those years served as round metal pipes.
At the beginning of the twentieth century, frames of a stamped profile with a rectangular section were very popular. Closer to the 30th of XX century, many companies-manufacturers of motor vehicles refused to use frames in favor of self-supporting body. In today's frame chassis are used mainly on trucks with a platform and tractors, but most frame structures are equipped with many SUVs and limousines.
Any automobile frame is characterized by a distinctive feature in terms of design. It consists in the distribution of functions of the carrier parts of the body and its panels, which have a decorative value. Decorative panels can also be equipped with reinforcing frame. Such a skeleton can be located, for example, in the area of the door openings, but in this case it does not participate in the perception of the force loads that make itself felt during the movement of the car. The most common is the classification of car

frames depending on the carrier structure used. There are spar, spine, peripheral, lattice frames (spatial), as well as bearing designs integrated into the body. The frame structure of the body will be considered in the work; therefore it is advisable to present their advantages and disadvantages.
Advantages:
– the frame is fairly simple in terms of the design of the bearing bodies and has well-worked out calculation methods;
– when applied on a passenger car, separate from the body frame allows you to enhance its comfort, providing better isolation from vibrations and noise coming from aggregates and tires;
– the frame is considered more suitable for the perception of heavy loads, for example when used on a truck or a "real" SUV;
– various modifications and even cars can be built on the same frame;
– the frame structure simplifies the assembly of the car at the plant, resulting in lower cost - all the main units are assembled on the frame, after which it is attached to the body in the assembly, which is easier than attaching the units separately on the body;
– an important advantage of the frame design of the car is that in such a car, after long journeys on bad roads, there will be no skewed door openings and cracks in the windshield racks, a longer durable running gear;
– in a frame car, the tendency to roll over is slightly lower than that of a car with a bodywork body.
Disadvantages:
– the distribution of the functions of the frame and the body leads to a substantial increase in the weight of the car compared with the carrier body configuration, which results in an increase in fuel consumption, and more load on the engine and transmission, and worse dynamic figures;
– frame cars, as a rule, at even (comparable dimensions, mass, class of cars) have worse passive safety due to difficulties with the creation of zones of programmed deformation.
One of the most common pickups on the Ukrainian car market is the Mitsubishi L200 (Fig. 1) [3].
There are such generations of Mitsubishi L200: Mitsubishi L200 I (1978-1986); Mitsubishi L200 II (1986-2000); Mitsubishi L200 III (1996-2006); Mitsubishi L200 IV (2006 is our time); Mitsubishi L200 V (2015-present time). At the end of 2014, the new generation of Mitsubishi L200 debuted at Los Angeles Auto Show. The car arrived in 2015 and is offered in the suite of Double Cab 4WD, Double Cab 2WD, Single Cab 4WD and Single Cab 2WD. Optional Super Select 4WD-II or Easy Select 4WD, or rear-wheel drive.
Undoubtedly this is a good car, but in recent years many photos can be found on the network, on which the naked eye can see serious problems associated with the frame.

Fig. 2: Illustration of damage to the Mitsubishi L200 IV frame

Fig. 3: Damaged frame

The main cause of this fracture is the corrosion of the frame, which is caused by the peculiarities of the design of the car body.
As you can see from Figure 3, the metal frame, which is the basis of the whole car is badly damaged by corrosion, is already unable to perform its functions without fail and needs to be replaced or repaired.

1.3. The aim

The purpose of scientific work is to study the expediency of using composite materials for the manufacture of a car frame.
To achieve a specific goal, the following main tasks need to be addressed:
– carry out analysis of loads on the car frame.
– to develop a basic scheme for calculating the loads and the study of stress, displacement and deformation in the frame.
– carry out studies on loading, displacement and deformation and compare them to different frame materials.

2. Main body

2.1. Description of the method of repairing the frame

The above problem is not new and there are methods of solving it without replacing the frame: in the problem areas, welded special MIG welding welds.
Having examined such a way of repair, we see a number of shortcomings:
– a large heating area. Places to the place of welding, thermally unstable items may be damaged due to the increased heating area;
– when the connection of metal in a thickness of more than 3 millimeters (thickness of the patch) occurs in the voltage in the metal, which can lead to deformation and destruction of the welding site;
– the slow heating and cooling of the welded surfaces leads to a deterioration of the metal structure of the welded frame, which results in we get worse strength characteristics.

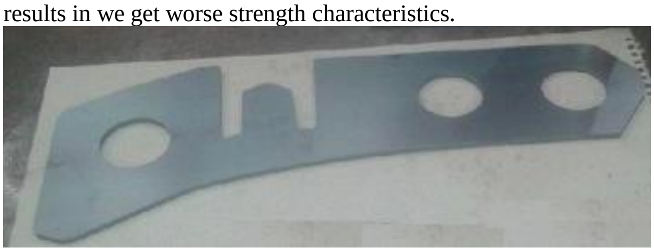


Fig. 4: Frame Bag

Fig. 5: Refurbished frame

It is proposed to replace this problem with a frame made of composite materials.

2.2. Description of the method of repairing the frame

There are many materials that can be used in the car body and chassis [4-10], but the main issue here is reliability and durability.
Unlike many natural and artificial materials that accidentally find application only after they have been discovered or invented, composites are often carefully designed taking into account the particularities of application. From the mid-20th century they began to develop both light and durable materials for the aerospace industry, and now they have found their way to a wide range of products, from secret bombers to smart cars and from bridges to oil platforms.
Future cars need to be safer, more economical and more environmentally friendly, and composites can help achieve these goals. Although composites such as GRP have been used in the production of automotive parts since the 1950s, most cars are still made of steel. Engineers believe thoroughly crafted composites can reduce the weight of a typical steel car by 40%, increasing fuel economy by one quarter, but maintaining body strength and emergency stability. High-temperature ceramic matrix composites also make it possible for cleaner engine motors for cars and trucks. Apart from the fact that the composites are lighter and stronger, they can provide better performance than metals at high temperatures and do not develop potentially hazardous weaknesses such as fractures and fatigue.
There are many materials that were explored for use in 3D printing for automotive industry, and today they have a dominant role in this niche:
– **ABS –** can take many different polymer forms, it can provide many different properties. On the whole, it is durable and more palatable than PLA plastic. Natural ABS has to beige color (milk) shade. The plasticity of ABS makes it easy to create elements of different joints and fasteners. It is easily polished and processed. It is important to note that ABS dissolves in acetone, which allows you to glued parts and achieve a very smooth surface.
– **PLA –** plastic is created from a variety of agricultural products - corn, potatoes, sugar beets, etc. - and is considered more environmentally friendly than ABS, which is based on oil. It was originally used to make food packages and is easily utilized in industrial composting plants. In a compost heap at your cottage he will not decompose - check PLA for longevity. In its natural form, it is transparent and colorful, which can also achieve a different degree of transparency. The PLA is as strong, but harder than ABS, making it more difficult to use for joints of various elements. Printed objects tend to be smoother. PLA is a bit harder to grind and handle than ABS. The lower melting temperature makes PLA unsuitable for a number of situations - for example, in a day in a heated car interior parts of it can be deformed and "sweat". PLA is dissolved in dichloromethane.
– **SBS –** strength, ductility and heat resistance make it a material that is often preferred in engineering and mechanical applications. The modulus of elasticity is much less than ABS. That is, the printed parts are more flexible. Extension at break> 250%. The thread, unlike ABS, does not break, let alone PLA, which is the brittle of the materials considered. SBS has a flexible structure. It does not break down and will not break when printing. Even if the rod in your extruder is supplied at an angle of 90 degrees! Material is transparent (93% light transmission). Coloring the material gives a very good effect. SBS is ideally suited for printing ceiling lights, prototype transparent dishes, bottles, etc. Processed and dissolved by limonene, dichloromethane, solvent.
– **ASA –** production, which requires the maximum degree of molded product extraction. Resistant to dilute acids, mineral oils, diesel fuel. Heat-resistant grades are designed for the automotive industry, impact resistant for engineering structures, extrusion options for window profiles.
– **PBT** – Polybutylene terephthalate - a polymer that crystallizes, refers to a highly polyester saturated polymer. Has become widespread as structural plastics. Areas of its application include machine building, automotive, electrical engineering and electronics, radio engineering, precision mechanics, household appliances, consumer goods. The use of polybutylene terephthalate as a structural thermoplastic material is associated with its basic properties and the possibility of various modifications of the material.
– **PC –** Polycarbonate is used successfully for the manufacture of panels of devices, connectors, electrical goods, cases of home appliances, etc. A distinctive feature of polycarbonate is that it allows you to receive transparent products with high durability and rigidity. It can withstand considerable shock loads and does not lose its operational qualities when operating in a wide temperature range.
– **POM** – Unlike other plastic masses, polyacetal combines high stiffness and sufficient hardness of polymer monolith with good resistance to dynamic, especially shock, loads. It does not lose its properties at low temperatures.
– **PSU –** Structural amorphous material, which has high thermal stability, good electrical and mechanical properties. There are transparent materials with a yellowish-brown tint. It can work for a long time at temperatures up to 160 ° C, and for a short period of time withstands heating up to 200 ° C. It withstands cooling to minus 100 ° C. For polisulfone is characterized by small shrinkage, even in formation. Therefore, the material is used for products with small landing tolerances, used for precision castings and products with complex configuration. The material has good mechanical properties - high tensile stress, elasticity and bending strength. Polysulfone is resistant to the action of alcohols, oils, lubricants, aliphatic hydrocarbons, saline solutions, mineral acids and alkalis.

2.3. Examples of composite materials used in automotive industry

The first concept with a composite body was the Dodge Intrepid ESX III introduced in 2003.
From the outside - a full-fledged family five-seater sedan of the middle class. For an economical car, the "slimming program" is absolutely necessary. Competitors lowered the weight of their concepts due to the widespread use of aluminum and magnesium alloys - light, but expensive. The Dodge ESX III body is made primarily of plastic. The corporation emphasizes: this is not expensive space frame with plastic sheathing, namely a load-carrying plastic body consisting of only 12 parts (in their steel about a hundred), in which integrated reinforcing elements from aluminum are integrated. Compared with steel, such a body is 46% lighter, 15% cheaper in production, and moreover, it has a higher rigidity (the latter is kept in the temperature range from -40 ° to + 100 ° C). The body parts are durable, painted in mass and 80% recyclable.

2.4. Mathematical modeling of the performance of a frame made of composite materials

2.4.1 Review of existing loads on the pickup frame

General view of the Mitsubishi L200 frame

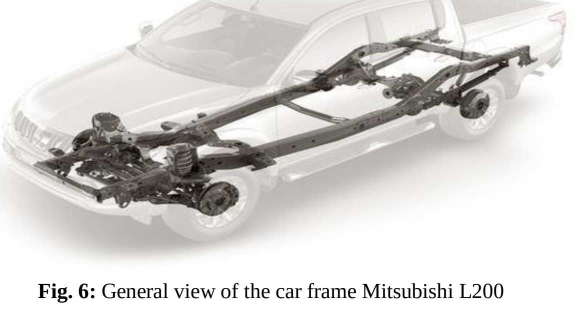


Fig. 6: General view of the car frame Mitsubishi L200

From Figure 6 we see that the frame has a complex shape and variable cross-sectional area along its entire length.
The frame takes over the load that acts on the car and transmits it to the road surface through the details of the suspension.
On the pickup frame there are the following loads:
– own weight of the car;
– weight of passengers;
– weight of the load in the cargo compartment;
– load from the trailer;
– fluctuations caused by the torque of the engine;
When calculating the frame, we exclude its twisting from the torque of the motor, since its size is so small that it can be neglected [11].
The most loaded part (point of concentration of stresses) of the frame is the connection of the load compartment and the body [12 - 13].
At this point most often damage to the frame, which leads to its loss of performance and complete replacement [14].

2.4.2 Choose the modes of operation of the car frame for calculations

In this paper, we examine 2 variants of the frame of the car:
– lightweight (the car is in place without cargo and passengers);
– maximum loads (in the car there are 5 passengers, their luggage is located in the cargo compartment and the trailer is loaded to the car with a carrying capacity of 650 kg).

2.4.3 Images of loads, and their character of action

To determine the load distribution on the frame, use the diagram shown in Figure 7

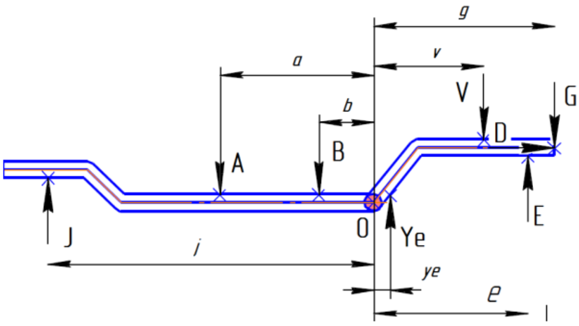


Fig. 7: Scheme of load on the frame

The diagram shows the existing load on the frame, the vectors of their actions and their location relative to the point of destruction of the frame.
The forces A and B are the weight of the passengers, we accept equal to 80 kg, the weight of the cargo in the cargo compartment is 500kg (5000N), G axial load, for each trailer is different, for calculations we accept 50 kg, that is 500 N, D load from the trailer, E counter force from the rear of the springs, there is from the front of the springs, and the opposing force from the front suspension, in addition to these forces, one should not forget about its own weight of the car, which is 1910 kg.
Force D is:

$$D = VP / 2 \cdot f \cdot \eta \quad (1)$$

where f - coefficient of rolling resistance of the wheel on the road surface.
For calculations we assume that the car is on the road with asphalt-concrete coating, which is in a satisfactory condition, therefore f = 0,02.
η – coefficient of resistance of rotor of a bearing of a hub of a trailer which is in the range of 0,95 - 0,995 for calculations we choose 0,98.
So substituting the values we get:

$$D = 650 / 2 \cdot 0{,}02 \cdot 1{,}02 = 66{,}3 H. \quad (2)$$

The formula for calculating the deformation of the frame is as follows:

$$A = \int_0^L \sum M \cdot d\varphi, \quad (3)$$

where $\sum M$ – the sum of all moments of the forces acting on the frame of the car.
To calculate the moment you need:

$$M = F \cdot L, \quad (4)$$

where F – the magnitude of the acting force,
L – the shoulder, through which the load occurs relative to the calculation point.

2.4.4 Investigate load on the frame with easy operation

The car only has its own weight, which is equal to 1910kg, that is 19100 N, but as we consider for calculation, then its own weight will be 19100/2 = 9550 N, and it is distributed with a calculation of 60/40 (60% load on the front axle, and 40% on the rear):

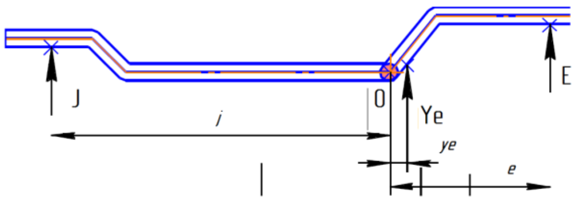


Fig. 8: Scheme of load on the frame when studying in easy mode of operation

$$\sum M_0 = F_V \cdot 0{,}6 \cdot (-J \cdot j) + \\ + F_V \cdot 0{,}2 \cdot (-Ye \cdot ye) + F_V \cdot 0{,}2 \cdot (-E \cdot e) \quad (5)$$

In the manufacture of frames, alloyed steel is used, its main characteristics are given in Table 1.

Table 1: Characteristics of alloyed steel.

№	Property	Values	Unit of measurement
1	The elastic modulus	210000	N / mm^2
2	Poisson's coefficient	0,28	
3	The shear modulus	79000	N / mm^2
4	Mass Gustik	7700	kg/m^3
5	Tensile strength	723,83	N / mm^2
6	Compressive strength		N / mm^2
7	Yield line	620,42	N / mm^2
8	Coefficient of thermal expansion	0,000013	K
9	Thermal conductivity	50	W/(m·K)
10	Specific heat capacity	460	J/(kg·K)

Calculating formula 5 load we get the stress in the frame listed in Table 2.

Table 2: Tension in the frame.

№	SX	SY	SZ
1	62779100	-851355	-32136500
2	76667200	-2507530	-389155
3	77799200	-36708,10	43568,70
4	-11759,40	8889,10	2758,97
5	-6209,44	4108,69	493,15
6	-22764,10	-40896,50	320,12
7	15365,90	-14368,70	1964,13
8	11984,60	-10590,80	-1328,38

9	136515000	3594100	-34746100
10	152561000	-69595	-89725,90
11	152512000	-2719300	-32355500
12	209576000	-74164,50	-111080
13	213996000	-3831640	34003900
14	70245100	3675490	-33540200
15	210314000	-3233940	31038000
16	201975000	2457080	-34192600
17	204031000	-440566	32145,60
18	273030000	3285320	-37526900
19	34551500	-24238100	-54836,30
20	292566000	-2743100	34078000
21	112082000	-41613,20	22530,40
22	95921300	-957035	-32108000
23	110889000	-1032940	-31955800
24	110845000	-2494960	-307764
25	-293736000	-461385000	-2680930

According to the table, a graph of stresses was constructed (Figure 9).

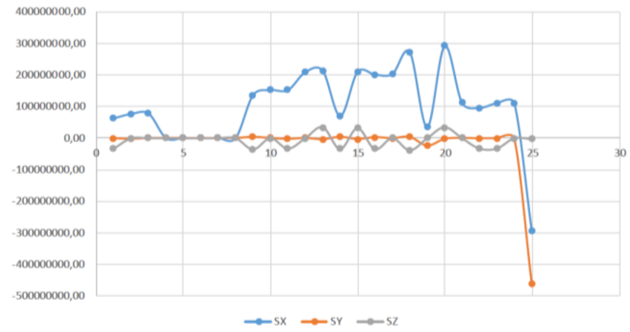


Fig. 9: Voltage chart in a steel frame made of alloyed steel.

After analyzing the graph, we see that the highest values of stress coincide with the conventionally accepted point of concentration of stresses and achieve maximum values in it.

Table 3: Moving in frame.

№	UX	UY	UZ
1	0,501547	-5,03911	-0,004791
2	0,501509	-5,03232	-0,00457886
3	0,501459	-5,02991	-0,00433874
4	0,501404	-5,03228	-0,00409556
5	0,501328	-5,03918	-0,00388412
6	0,50894	-5,03918	-0,00482968
7	0,508984	-5,03228	-0,00459659
8	0,509039	-5,02991	-0,00433518
9	0,50909	-5,03232	-0,00407865
10	0,509161	-5,03912	-0,00386602
11	0,00003186	0,00005799	0,00030601
12	0,00001554	0,00002899	0,00030578
13	-0,00000079	-0,00000286	0,00030571
14	-0,00001713	-0,00003482	0,00030577
15	-0,00003344	-0,00006339	0,00030602
16	-0,00003339	-0,00006339	0,00030875
17	-0,00001708	-0,00003482	0,00030905
18	-0,00000078	-0,00000286	0,00030912
19	0,00001552	0,00002899	0,00030905
20	0,00003183	0,00005799	0,00030883
21	1,06557	-5,0413	-0,00426085
22	0,986048	-5,0405	0,0202181
23	0,906589	-5,0399	0,031295
24	0,827115	-5,03957	0,0333479
25	0,747639	-5,03923	0,0287717

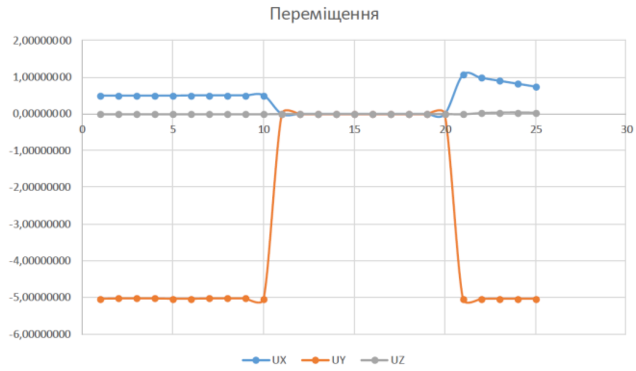


Fig. 10: Graph of moving in a frame that is made from alloy steel

The graph shows the distribution of displacements in the working section for steel. In the most loaded section it is evident that the movements are quite significant.

Table 4: Deformation in the frame.

№	EPSX	EPSY	EPSZ
1	0,0000021176	-0,0000069285	-0,0000029295
2	0,0000017587	-0,0000179003	0,00000642655
3	-0,0000005114	-0,0000014193	-0,0000014076
4	0,0000039892	-0,0000134538	0,00000261690
5	-0,0000000502	-0,0000016400	0,00000442371
6	-0,0000005577	0,00000017870	-0,0000004641
7	0,000001963	0,00005311580	-0,0000190776
8	0,00000007619	0,00000009913	-0,0000001573
9	0,00000726005	0,00009972390	-0,000221044
10	-0,0000000718	0,00002972260	-0,0000126744
11	0,00000023321	0,00000012650	-0,0000001316
12	0,00001248560	-0,000169097	0,00006123910
13	0,00000550403	-0,0000850156	0,00003171850
14	-0,0000000448	-0,0000000426	0,00000003760
15	0,00000507425	-0,0000248001	0,00001062720
16	0,00000012962	0,00000006509	-0,0000003350
17	0,00000676571	-0,0000848454	0,0000306011
18	0,00000122220	0,00005114680	-0,0000185691
19	-0,0000041801	0,00018992700	-0,0000713743
20	0,00000171370	0,00002872980	-0,0000757204
21	-0,0000035207	-0,0000235193	0,0000652605
22	-0,0000023814	-0,0000003221	0,0000085732
23	0,00000034503	0,00002142030	-0,0000560001
24	-0,0000036000	-0,0000351243	0,0000845253
25	-0,0000039897	-0,0000289228	0,00008710130

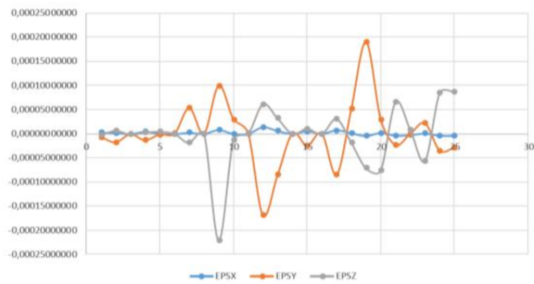


Fig. 11: Graph of deformations in a frame made from alloy steel

The following calculations are conducted similarly to the presented and we will add to the applications A, B and B.

3. Modeling and researching a frame in the SolidWorks Simulation system

SolidWorks Simulation is a structural analysis system that is fully integrated with SolidWorks.

SolidWorks Simulation provides voltage analysis, loss of stability, optimization, and frequency and thermal analysis on one screen. Equipped with fast decoders, SolidWorks Simulation lets you quickly solve large tasks using your personal computer. SolidWorks Simulation comes with several packages to meet your analytical needs.

SolidWorks Simulation shortens design costs by saving time and effort when looking for the optimal solution.

For a complete study, a three-dimensional model of the frame of the frame was created, and it provided real properties to ensure the accuracy of the results.

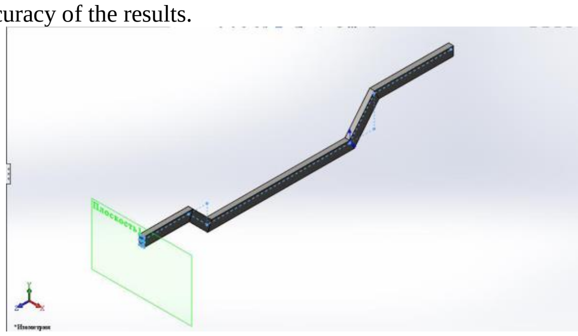


Fig. 12: Model of a spar box frame for static studies

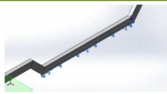
Properties	
Name:	ABS
Model type:	Linear Elastic Isotropic
Strength criterion default:	Undefined
Yield strength:	3e+007 N/m^2
Tensile strength when stretching:	7.23826e+008 N/m^2
Elastic modulus:	2.1e+009 N/m^2
Poisson coefficient:	0.394
Mass density:	7700 kg/m^3
Shear modulus:	7.9e+010 N/m^2
Coefficient of thermal expansion:	1.3e+005 /Kelvin

Properties	
Name:	ABS
Model type:	Linear Elastic Isotropic
Strength criterion default:	Undefined
Yield strength:	3e+007 N/m^2
Tensile strength when stretching:	7.23826e+008 N/m^2
Elastic modulus:	2.1e+009 N/m^2
Poisson coefficient:	0.394
Mass density:	1020 kg/m^3
Shear modulus:	3.189e+008 N/m^2

Fig. 13: Properties of materials for two studies

After selecting the materials, it is necessary to fix (limit movement) and apply the load on the object of research.

Loads and Fixex

Fix Name	Image	Fixing data
Fixed - 1		

Resulting forces

Components	X	Y	Z	
Reaction Force (N)	-0.890157	247.563	0.300911	247.565
Reactive moment Nm	0	0	0	0

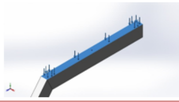
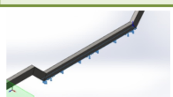
Load name	Image	Load data
Force -1		Value: 248 N

Fig. 14: Fixing and applying loads to the metal frame.

Loads and Fixex

Fix Name	Image	Fixing data
Fixed - 1		

Resulting forces

Components	X	Y	Z	
Reaction Force (N)	-0.109845	247.953	-0.810417	247.955
Reactive moment Nm	0	0	0	0

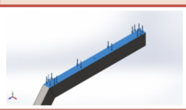
Load name	Image	Load data
Force -1		Value: 248 N

Fig. 15: Fixing and applying loads to the composite frame

After performing the above-mentioned manipulations, you can begin to conduct research and obtain results.

3.1 Simulation of stresses

Having studied the stress test in the simulation application, we get the result:

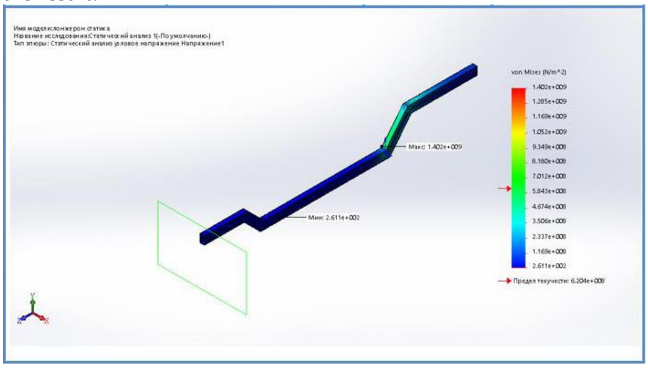


Fig. 16: Voltage for a metal frame

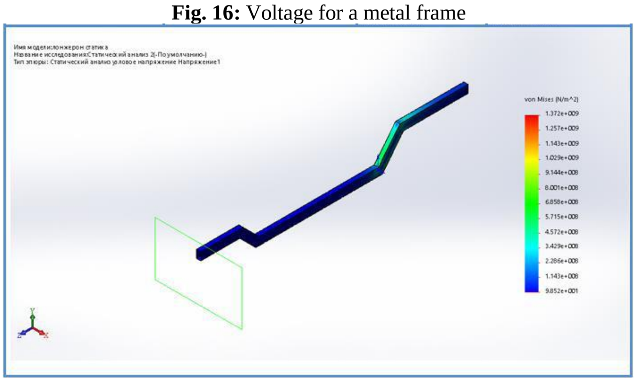


Fig. 17: Voltage for a composite frame

From Figures 16, 17 we see that the mathematical calculations for stress are fully confirmed by experimental studies.

3.2 Simulation of displacements

Having obtained the result in the simulation application in finding the displacements: Figures 18,19.

From Figures 18, 19 we see that mathematical calculations on displacement are fully confirmed by experimental research.

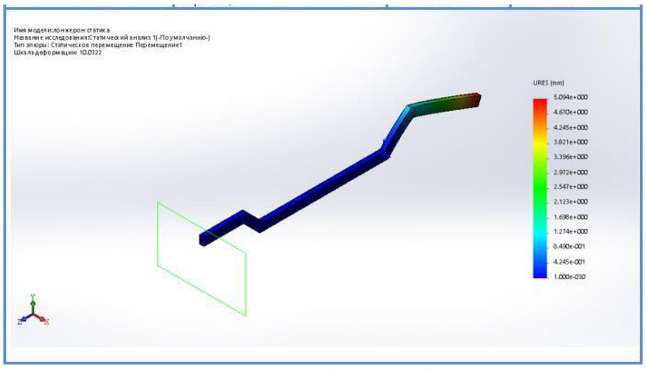


Fig. 18: Moving for a metal frame

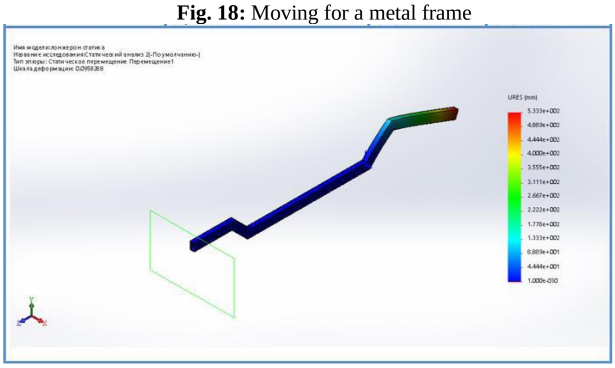


Fig. 19: Moving for a composite frame

3.3 Modelling of deformation

When conducting a deformation study we see how deformable the frame is under the action of given loads:

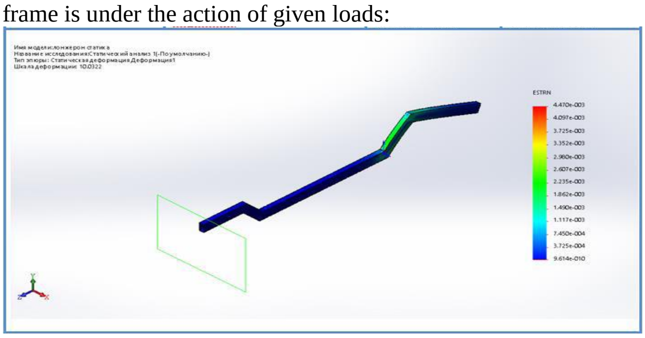


Fig. 20: Deformation for a metal frame

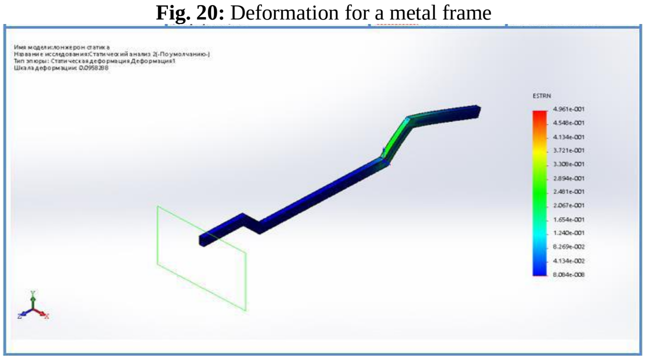


Fig. 21: Deformation for a composite frame

From Figures 20, 21 we see that mathematical calculations on deformations are fully confirmed by experimental research.

4. Conclusions

1. The passenger cars frame structures advantages and disadvantages analysis gives grounds to assert that the separate frame of the body raises their comfort, providing isolation from vibrations and noise, allows to increase the carrying capacity, more technologically at the assembly of the car at the plant due to the previous attachment to it of the aggregates, reduces body metal due to the dynamic frame load perception, etc. However, the frame structure of the car has a significant drawback - an increase in the metal capacity of the vehicle.
2. One of the ways to reduce the car metal capacity a while ensuring rigid and solidity frame characteristics can be the composite materials for its manufacture use.
3. Car frame damaged parts are mainly repaired by welding metal packs. At the same time, due to welding in the welding sites, the structure of the metal frame is broken there are stresses after the metal cooling, etc. Therefore, when repairing the frame or when manufacturing new parts for automotive industry, it is offered to use 3D-printing from the composite materials offered in this article.
4. SolidWorks Simulation, fully integrated with the SolidWorks software shell, conducted frame stresses and displacements analytical studies from the proposed composite materials.

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