Application of finite element analysis in the development of the pedal assembly of the Formula Student racing car

Alexander V. Bobrowskii, Alexey V. Zotov*, Dmitry A. Bobrowskii, Mikhail P. Gololobov, and Ekaterina D. Chizhatkina

Togliatti State University, Belorusskaya Street, 14, Togliatti, Samara Region, 445020, Russian Federation

Abstract. The study is focused on presenting an assessment of additive manufacturing usage in modern technological processes, including the manufacturing of parts of the racing car participating in Formula Student project. It shows the necessity of simulating physical processes during the design stage using the finite element analysis. The issues of calculating the strength of pedals of various functional purposes are considered. The boundary conditions imposed on the accelerator pedal are presented. It was found that loads applied with an offset to the edge of the support platform cause higher stresses in the item. The distribution patterns of the safety factor of an accelerator pedal created by additive method from materials: acrylonitrile butadiene styrene, polyamide Nylon 6/6 and polyamide Nylon 6/6 reinforced with fiberglass are presented. The results of modeling the rigidity of the pedal structure and the maximum stresses arising in it under load are indicated. The results of simulation of the prefabricated structure of the accelerator pedal with an aluminum alloy lever with a pedal plate obtained by additive manufacturing are shown.

1 Introduction

In order to minimize technical work aimed at creating original parts, there is a need in modern production to use universal technology and universal equipment. Today, one of the promising areas in the automotive industry is the use of additive technologies that reduce production labor costs and allow to reproduce parts with a complex geometric shape. The most widely used technology at the moment is Three-Dimensional Printing (3DP) with layer-by-layer additive manufacturing (AM) [1]. It makes it possible to shorten the design cycle of a single component. In other words, the focus is on building a product quickly, while saving significant time by eliminating the need to design tooling to produce modeled parts. The result of applying AM is a physical product. Engineers use this technology to create a physical model using only digital data. For enterprises with continuous production, the use of AM as the main technology is unacceptable due to the large time spent on creating one unit. AM has found wide application in the production of prototypes, as well as in one-off

* Corresponding author: A.Zotov@tltsu.ru
custom production, including parts for racing cars developed as part of the engineering student project Formula Student [2, 3].

Meanwhile, before implementing parts obtained by additive manufacturing, it is necessary to prove its functional ability, which can be done using Computer aided engineering (CAE). CAE is a software designed to solve engineering problems, namely the simulation of physical processes in a product under the influence of external factors, their analysis and calculations. This type of software works in conjunction with Computer-aided design (CAD) complex which performs analysis based on geometric constructions.

2 Relevance

In the vast majority of cases, the units’ strength at the design stage of the Formula Student racing cars is assessed using the finite element analysis (FEA). Among other things, the use of computer simulation and analysis in the study of the structural strength of car pedals of various topologies is quite widespread [3–8]. Thus, in [3], the strength of the Formula Student car’s accelerator pedal made by AM from ABS plastic was studied using FEA. In this case, the deformation was 4.77 mm at a load of 150 N. In [4], the steel structure of the accelerator pedal was optimized using the finite element analysis, and the authors of [5] chose aluminum alloy as the pedal material, and the design was also optimized using FEA. The paper [6] demonstrates the possibility of using AM for a metal car brake pedal of a rather complex configuration with strength control by the finite element method. At the same time, the values of local displacements recorded during physical tests were lower on average by 8 % compared to the calculated data obtained through FEA. The authors of [7] modeled the brake pedal in the CATIE geometric modeling environment and analyzed the structural strength in the ANSYS package. The use of polyamide with short glass fiber as the material of the pedal allowed to reduce the weight by almost 70 % and at the same time provide sufficient strength. The authors of [9] investigated cases of breakage of the accelerator pedal levers of a car with a matrix of polypropylene reinforced with long fiberglass. It was revealed that the result of the breakdown was the concentration of stresses at the place where the pedal was attached to the frame.

3 Finite element analysis

Until recently, Formula Student racing cars developed by Togliatti Racing Team (TRT) had an accelerator pedal in the form of a prefabricated metal structure. Each individual part included in the design required a full cycle of design work, which, among other things, consists of: a model, a drawing of each part, assembly drawings, an installation drawing, a technological map, an operating map, manufacturing on metalworking equipment and a final measurement map.

At the moment, TRT is working in several directions at once, the purpose of which is the development and manufacture of pedals with a small mass and at the same time high strength and in accordance with the rules of the Formula Student project.

One of the directions is the production of a full-bodied accelerator pedal by FDM printing on a 3D printer.

For comparative analysis, taking into account the operating conditions of the accelerator pedal, polymers such as acrylonitrile butadiene styrene (ABS), polyamide Nylon 6/6 and polyamide reinforced with Nylon 6/6 GF glass fiber were selected.

The ANSYS software package was chosen as the main mathematical environment for calculations.
The calculation was carried out in two steps: when a force was applied in the center of the support platform and when it was shifted to the edge of the platform, to simulate an asymmetric pressing of the accelerator pedal during movement. The analysis took into account the calculations for the deformation of the structure, its stress state and the margin of safety of the product.

By practical consideration, it was found by TRT that a force of 70 N is required to open the throttle, which is consistent with studies [10]. It should be noted that this effort is optimal, however, the driver in the cockpit of a racing car can sharply press the pedal with a force of up to 200–250 N, which exceeds the calculated value by several times.

Figure 1 shows the boundary conditions imposed on the product.

![Fig. 1. Boundary conditions.](image)

The direction of the force vector of 250 N is indicated in the center of the support platform and with an offset to the edge. A force of 13 N which returns the pedal to its non-working position is also indicated. Along the attachment axis on the pedal assembly, fixation is set in the axial and radial directions with the possibility of rotation around the axis. On the rear wall of the pedal, a limit is set on the heel of the stop, which limits the pedal travel.

The results obtained show that loads applied with an offset to the edge of the support platform cause higher stresses in the product, so the comparison of materials was carried out based on these data.

Figures 2–4 show the results of the simulation, and exactly the margin of safety of the structure.

The deformation value of the ABS pedal is 4.7 mm, Nylon 6/6 is 6.3 mm and Nylon 6/6 GF is 1.36 mm.

As reflected by figures, the pedal made of Nylon 6/6 GF showed the best result – the value ensures that there is no contact between the parts of the car. In the automotive industry, during the initial 3D layout, a gap of 3 mm is laid between the parts, because during the physical embodiment of the design, this size tends to zero due to the impossibility of perfectly accurately reproducing the overall dimensions of the part. Based on existing technology, there is always room for error.

The value of the specified maximum stresses for the pedal structure made of ABS plastic is 33.8 MPa, Nylon 6/6 – 27.8 MPa and Nylon 6/6 GF – 28.3 MPa.
As can be seen, the pedal made of Nylon 6/6 showed the best result, while the Nylon 6/6 GF one showed the most by 0.5 MPa.
The margin of safety is defined as the ratio of the yield strength of the material to the maximum stresses in the structure. The higher the value of the obtained safety factor, the more the finished product is able to resist external loads.

The calculation for ABS plastic showed a minimum value of 1.22, for Nylon 6/6 – 2.05 and for Nylon 6/6 GF – 4.91. At the same time, for a full comparison it is necessary to consider the mass of products. So, the weight of the pedal made of ABS was 226 grams, Nylon 6/6 – 248 grams, Nylon 6/6 GF – 296 grams.

As a result of the comparative analysis, the pedal made of Nylon 6/6 GF showed the best result.

Another direction is the development of an accelerator pedal with a lever made of aluminum alloy with a pedal plate obtained by AM on a 3D printer.

In order to optimize this design, a series of strength tests were carried out on the pedal plates. The first sample was made of HIBS plastic – high-impact polystyrene which stands out due to its easy processing and low shrinkage. The second sample was made of PETG plastic – polyethylene terephthalate, which is more durable and wear-resistant than PLA and ABS, but due to its fluidity, it requires good preparation of a 3D printer. The third sample was made of PLA plastic, which does not shrink and has high strength, but is brittle and deforms when heated from 50 degrees.

These samples were tested for strength on a universal machine H50KT for compression and tensile tests.

Nylon 6/6 and Nylon 6/6 GF were not considered as materials for the pedal plate due to the need to use a special 3D printer and a fundamentally different pattern of its loading.

The HIBS plate showed the lowest strength with a peak value of 1712 N, the PLA plate – 7840 N, the PETG one – 10375 N, which is the best test result for strength and low deformation compared to other plastics.

The PLA plate was chosen, since PETG plastic takes more time to prepare a 3D printer and has more shrinkage, which lowers the quality of manufacture and increases the time to optimize the part. PLA does not require a heated table, which eliminates shrinkage of the plastic and part dimensions while still providing sufficient strength.

In the manufacture of a solid part, PLA was not considered due to the low softening temperature, which could lead to deformations at the point of contact between the pedal and the steel axle.

Figure 5 shows the results of the finite element analysis (von Mises stress) of the prefabricated structure.

Fig. 5. Stress distribution over the product.

For the prefabricated structure, similar calculations were carried out as for full-bodied products when the same boundary conditions were applied. In this case, the deformation
when the load was shifted to the edge was 0.3 mm, the maximum stresses were 83.9 MPa, and the safety factor was 3.03.

The mass of the prefabricated structure was only 262 grams, which predetermined its inclusion in the final version when developing a racing car. Figure 6 shows the finished product.

Fig. 6. Finished product.

4 Conclusions

As a result, the pedal made of ABS showed the worst results in terms of stiffness and safety factor, but has the smallest mass of 226 grams. At the same time, the pedal made of Nylon 6/6 GF has excellent performance, but has the largest mass – 296 grams, which exceeds even the weight of the assembled pedal with the lever made of aluminum alloy and only the plate part of the pedal obtained by FDM printing (262 grams).

Despite the fact that the safety factor of a pedal made of Nylon 6/6 GF (4.91) is higher than that of a prefabricated structure (3.03), the second option was chosen for implementation in the Formula Student project. At present, it is difficult to assess the strength of products made by additive manufacturing due to the manifestation of anisotropic properties inherent in various options for the formation of the structure of these products, while the way aluminum alloy behaves is well predicted.

In the future, it is planned to continue research on reducing the mass of pedals by adding an outer layer of a composite material, which will increase the strength of the product, as well as conduct additional studies of strength characteristics depending on the print raster and print layers depending on the direction of the applied load.

References