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NUMERICAL VERIFICATION OF QUASI-STATIC STRENGTH OF THE HORIZONTAL BICYCLE WELDED FRAME

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Abstract

Horizontal bicycles can be classified as means of transport powered by one's own muscles that are in the lead as regards low aerodynamic drag, riding comfort and safety. This kind of construction is influenced by load that in the case of inadequately engineered bicycle frame may lead to the construction damage. To prevent this, strength and stiffness analyses are conducted whose boundary conditions correspond with these during real exploitation. Various extrusion profiles of the bicycle frame are connected with the use of welding technique which additionally makes us conduct analysis strength of welded joints. These kinds of calculations are carried out with the use of the software basing on the finite element method making it possible to gain stress and deformation values for complex cases of frame load and whose results cannot be obtained in an analytical way. The frame of the horizontal bicycle was put to analysis in the three different load variants. We achieved maximum deformation, stress in the critical points and in the welding joints of the frame, which then were compared to the allowable values. The correct verification of the received values contributed to determining joints vulnerable to damaging and modifying the frame construction to minimalize the possibility of its destruction.

Keywords*: finite element method, horizontal bicycle, welded joints calculation, strength of welded frame*

1. Introduction

One of the means of transport that doesn't consume any fuel, doesn't emit any pollution or make noise is a bicycle. It is easily accessible and widely used thanks to its simplicity, by all people who want to move only thanks to their muscles power [7, 9]. The strivings of the manufacturers and construction designers to reduce aerodynamic drag, improve comfort and riding safety contributed to the creation of horizontal bicycles. These are not numerous solutions and are used because of their constructions, which are often influenced by unpredictable loads [8]. The main strength problem for that construction is correct designing of a frame. That is the most important part ensure safe riding.

One of the features of a correctly applied mechanical construction is meeting the strength conditions, with boundary conditions corresponding to real exploitation conditions. In order to check them, the construction must be put to strength and stiffness analysis. In the case of the analysis of welded parts, it is necessary to carry out calculations of the welded joints. There are geometric and structural notches leading to the stress concentration and making the welded joints the weakest area of the construction. The analysis of such problems is very complicated as the strength of a given joints depends on many factors: welding stress, chemical composition of welded materials, process of welding, local change in mechanical characteristics within the heat influence range [1, 2]. Most of them are included in the standardized calculation algorithms by applying correct coefficients depending on the kind of welded joints, border of plasticity of the material of original joints [3, 5].

2. Static strength of welded joints

The calculations of welded joints in the process of designing consist in a correct determining of the size of the connection. That must ensure work safety of the construction. When designing welded joints, one should take into account the minimaliation of the connection size, simple shape and applying optimum production technique as regards its costs [2].

In order to design a welded construction, there are various norms that can be used to check the strength of welded joints. They include procedures used to calculate the strength of a construction such as Polish Norms (PN-90/B-03200 [3], PN-82/S-10052 [4]), Eurocode 3 [5]).

Static strength of welded joints is calculated according to the instructions contained in the above norms. For the purpose of this calculation, the norm [3] which defines the condition of strength for fillet welds in a complex state of stress was used (Fig. 1):

$$\sigma_{red} = \kappa\sqrt{\sigma_{\perp}^2 + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)} \leq \alpha_{\perp}\frac{R_e}{x} \tag{1}$$

where:

$\sigma_{\perp}$ - the normal stress perpendicular to the throat,

$\sigma_{||}$ - the normal stress parallel to the axis of the weld,

$\tau_{\perp}$ - the shear stress (in the plane of the throat) perpendicular to the axis of the weld,

$\tau_{||}$ - the shear stress (in the plane of the throat) parallel to the axis of the weld,

$\alpha_{\perp}$ - factor of strength weld.

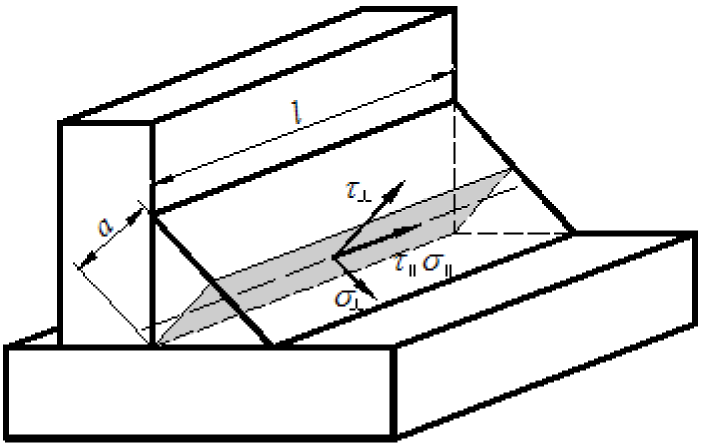

Fig. 1. Level of stress in fillet weld: a – calculation thickness of weld , l – length of weld [3]

3. Strength and stiffness analysis of the bicycle frame

Numerical analyses of stress and deformation were carried out with the use of ANSYS Workbench software that bases on the finite element method. The application of this method is connected with many conditions that influence final results connected with the possibility of a slight mistake. In order to eliminate this problem, numerical calculations for simple variants of this issue were carried out and these results were verified by analytical calculations. The parameters of the discrete model were defined (type, size of element, kind of stress) for which results with slight relative error were obtained. In the analysis of the complex model, the same parameters of the discrete model were applied.

The calculations of the complex problem were carried out for the construction of the horizontal bicycle frame consisting of closed sections made of aluminum 6061 (PA45) in the T6 state (R_e = 240 MPa). The profiles were connected by welded joints. The geometry and boundary conditions of the frame are presented in Fig. 2. The bicycle is powered by solar energy stored in a battery powering an electric engine [6].

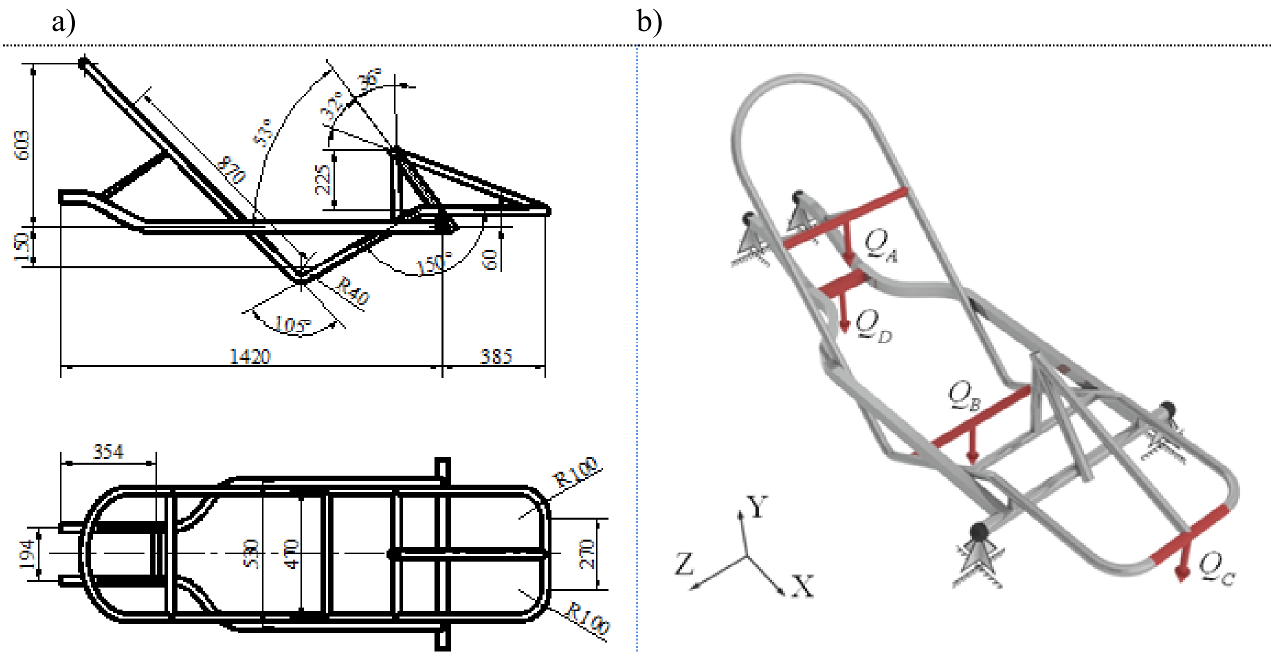

Fig. 2. A diagram of the frame: a) geometric features, b) boundary conditions (A ÷ D – profiles under load)

In the analysis of the bicycle frame, the supports are in the place of fixing wheels which were deprived of some freedom in the vertical direction and turn around this direction. The frame load results mainly from the cyclist's and battery weight (Q_D).

The stress value is strictly dependent on the cyclist body posture. A slight transfer of the body weight to the front or backwards will considerably change the frame load. During riding, it is also possible to change support points which take place while riding in standing position. Most of the mentioned problems, make it possible to define correctly load of the frame: mountain bikes, road bikes, bmx, etc.

In the case of the quasi-static bicycle analyze, the determination of load values is possible as the frame construction makes cyclist keep one position while normal riding (Fig. 4) additionally limiting body movements by the application of safety belts. In order to determine the distribution of forces exerted by a sitting person, the following measures were made: a person with a weight of mass m_r = 80 kg (average weight of an adult) sitting on a saddle-chair (Fig. 3). The leaning angles α_{B1}, α_{B3} correspond to the location of a saddle-chair in the designed bicycle [6].

The analysis was carried out for three different stress variants, when a cyclist:

1. Sits on a saddle-chair in a riding position.
2. Is in the process of getting into the saddle-chair load only the central part of the saddle-chair.
3. Is sitting on a saddle-chair of the bicycle, that is parked on a leaning area of 34° (maximum angle when the bicycle doesn't capsize).

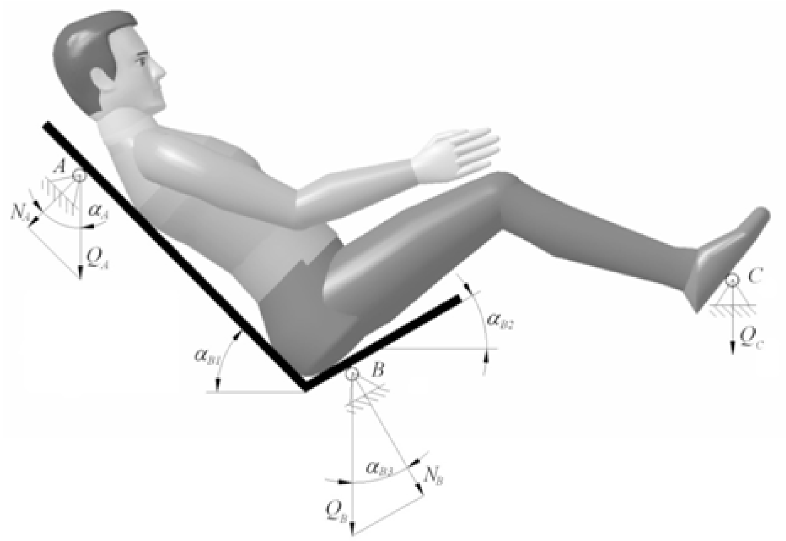

Fig. 3. A diagram of determing forces acting on the frame: $\alpha_A = \alpha_{B1} = 45°$, $\alpha_{B2} = \alpha_{B3} = 30°$

Table 1. Load values of the frame construction

Variant	Force [N]											
	Q_A			Q_B			Q_C			Q_D		
1	360			590			120			100		
2	0			1000			0			100		
3	0X	0Y	0Z	0X	0Y	0Z	0X	0Y	0Z	0X	0Y	0Z
	62	298	201	102	489	330	21	99	67	17	83	56

In the ANSYS Workbench software the strength and stiffness analyses for frame geometry modeled by shell elements (Shell181) were made. Example results in the form a distribution of deformation map are presented on Fig. 4. Reduced stress was determined for components of stress measured at the most strained parts of the frame (Fig. 5) and then compared to the allowable values (Tab. 2).

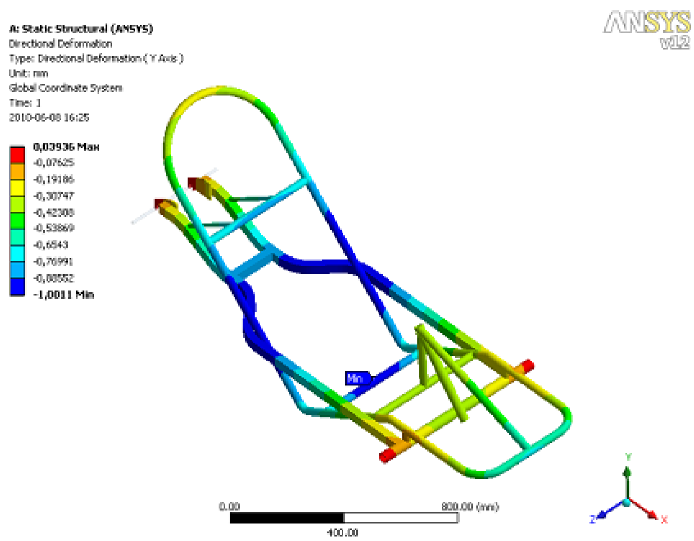

Fig. 4. A deformation map of the frame (variant 1)

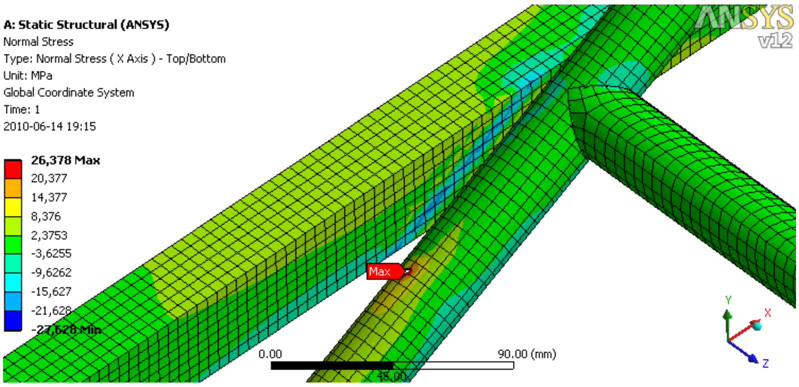

Fig. 5. A map stress in the place of maximum stress

Table 2. A comparison of stress values in the most strained point

Var.	Def. [mm]	Stress [MPa]							
		σ_x	σ_y	σ_z	τ_{xy}	τ_{yz}	τ_{xz}	σ_{red}	σ_{allow}
1	1.001	36.378	9.39	12.951	13.56	3.054	4.295	**31.023**	60
2	1.313	35.336	12.271	20.496	17.205	4.318	7.378	**31.041**	60
3	1.14	44.611	21.713	19.114	28.095	10.35	12.234	**46.473**	60

4. Strength of the welded joints

The next stage is the verification of the strength of welded joints. A new applied method was the method of determining stress in the welded joints, which is not well described in the subject literature. A procedure giving correct values of stress in welded joints of the bicycle frame has been worked out. The numerical calculations were based on the application of contact elements responsible for undividable surface connection in the place of welded joint. Correct application of the contacts led to a fast and simple reading out of the stress in the welded joints (Fig. 6), whose determination in an analytical way is very complicated.

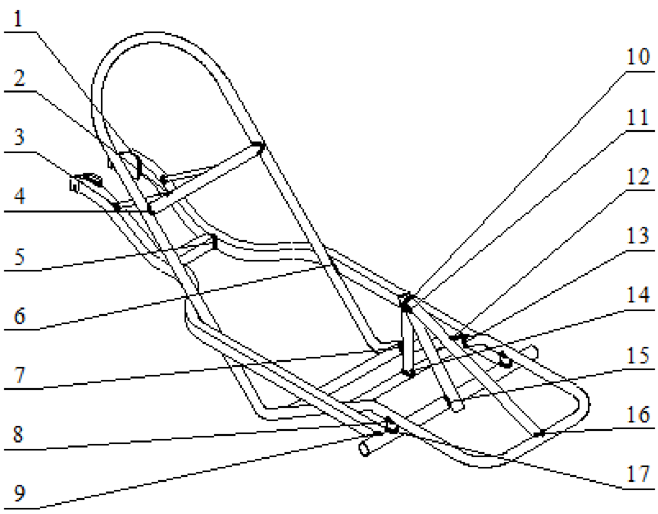

Fig. 6. The placement of welded joints in the frame construction

The values from the obtained distribution of stress in contact elements were averaged with the use of numerical integration. The obtained values for the most stressed joints were presented in Table 3. Reduced stress (σ_{red}) were compared to the allowable stresses.

Table 3. A comparison of stress values for the most strained weld joints

Nr	Stress [MPa]									
	variant 1			variant 2			variant 3			σ_{allow}
	$\sigma_{\perp}$	$\tau_{\parallel}$	$\boldsymbol{\sigma_{red}}$	$\sigma_{\perp}$	$\tau_{\parallel}$	$\boldsymbol{\sigma_{red}}$	$\sigma_{\perp}$	$\tau_{\parallel}$	$\boldsymbol{\sigma_{red}}$	
4	3.074	10.205	**12.559**	18.231	7.961	**16.001**	35.91	18.006	**33.294**	42
6	22.693	5.662	**17.305**	7.212	7.451	**10.349**	9.719	7.681	**11.533**	42
7	22.975	10.33	**20.384**	35.256	15.983	**31.378**	48.104	10.116	**35.837**	42
8	14.723	3.341	**11.074**	22.414	6.615	**17.621**	30.478	8.925	**23.922**	42
13	11.626	11.583	**16.231**	29.597	13.048	**26.067**	9.267	18.098	**22.881**	42
17	8.441	8.789	**12.185**	7.84	9.633	**12.905**	16.41	17.739	**24.383**	42

5. Summary

The frame construction of a horizontal bicycle was analyzed as regards its strength and stiffness For 3 different variants of boundary conditions. The stress and deformation values obtained from numerical analyses for frame geometry are within allowable values. The analyses verifying the strength of weldment have also been carried out. In order to do it, a procedure of determining stress in welded joints by applying suitable contact elements was prepared. Adequate processing of the results allowed us to obtain values with only slight mistakes, which proved the correctness of the applied method. The stress values in various welds are lower than the allowable ones. The analysis results showed a correct size of the applied frame sections in given conditions with static strain. To complete the construction calculations, dynamic analyses for strain occurring in extreme conditions are planned.

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