MULTI-PARAMETER OPTIMIZATION OF BRAKE OF PISTON

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Abstract: The aim of this study is to define optimal construction of brake piston (material, seal position) in caliper. Stress level and distribution, deformation and weight were examined to find optimal thickness where seal position (seal in caliper, seal in piston) was changed. Three materials were examined in finite element software (2D axisymmetric model): aluminium alloy (3.4335), steel (1.0039) and titanium alloy (3.7165). Pistons parameter tested: diameter 44 mm, height 29 mm, If the material is aluminium alloy the wall thickness is 2.69 mm, in case of steel the thickness is 4.02 mm when the seal is in the groove of piston. When the piston material is titanium alloy, the wall thickness is 0.8 mm having the seal in the caliper. The weight is critical issue in brake systems, so, the optimal wall thickness defines then piston weight. Weight of aluminium alloy is 0.045 kg, weight of steel is 0.153 kg and weight of titanium alloy is 0.047 kg. These weights show that aluminium alloy piston offer the lightest construction in case of maximum pressure 15 MPa.

Keywords: piston of brake, stress, deformation, mass, FEM

1   INTRODUCTION

Brake system (disc brake, drum brake) in vehicle is friction brake [7] where two parts press each other and make friction, which makes braking torque on wheel. The two friction parts slow down the car, furthermore these parts stabilize the vehicle. Usually disc brake was used due to the advantageous parameters, where friction parts are the brake disc and the brake pad. Usually hydraulic system was used in vehicles, which can move the pistons in brakes. These pistons press the brake pad to brake disc. Brake system converts the kinetic energy into heat-energy when vehicle slow down, The generated heat energy affects the brake system's parts. Many studies determined the heat affect in the function of coefficient of friction between brake pad and disc [10], furthermore set the differences of friction materials and suggest advantageous testing layouts the brake systems [9]. On the other hand, not only disc brake but drum brake [4] systems also were examined in more studies. Concerning the disc type brakes limited research data are available about the role of pistons, however the disc [1] and brake pad [8] more investigated. In several cases researchers ignored the piston's effect or pistons are not involved into the different test models. Many publications are about e.g.the stress distribution in the disc. Yildiz and Duzgun made finite element model where they have examined the disc's stress but they ignored the brake pad pressure distribution, which depends on pistons. The acting forces were modelled in different surfaces, but not properly simulating the effect of pistons mechanical behaviour under stress [13]. In other studies thermal behaviour was tested where temperature change was defined in function of time. Jung et.al. and Chung et.al. made simulations where piston was a simple disk and ignored the wall thickness of pistons that effect pressure distribution in brake pad's frictions surface. [11] [12] there some studies about the manufacture of pistons. Hwang examined the manufacture and design process but do not define why 6.40 mm wall thickness was used to piston's wall thickness. [3] The geometry of pistons can also influence the brake system parameters. Size and geometry of pistons were modelled having free movement of the deformed pistons in the caliper. Other idealistic approach in the model was the even pressure distribution on the friction surface and the weight of pistons was taken as small.

The aim of the present study is to define stress distribution, deformation, optimal weight and wall thickness in the disc brake systems, focusing on the role of pistons as well. These results show the optimal wall thicknesses of the pistons in case of three advantageous piston materials, aluminium alloy (3.4335), steel

(1.0039), and titanium alloy (3.7165). The proper piston design was important avoiding piston stick into the caliper. Geometry and material define the weight, which is important for the reliability during operation. High mass can result poor controllability. The suggested constructional materials have low density and high strength (2, 4, 6, 8), so, piston's material is relevant.

2   MATERIAL AND METHODS

Pistons material is important because the material influences many parameters of piston (weight, stress, deformation). It is necessary for piston to have low density and high strength. In this study aluminium alloy (3.4335), steel (1.0039), titanium alloy (3.7165) were compared. Parameters of these materials are in Table 1.

1. Table: Properties of piston's material

	Aluminium alloy (3.4335)	Steel (1.0039)	Titan alloy (3.7165)
Density	2.77 g/cm^3	7.85 g/cm^3	4,62 g/cm^3
Tensile Strength, Yield	280 MPa	251 MPa	930 MPa
Young modulus	71.7 GPa	210 GPa	96 GPa
Poisson ration	0,33	0,3	0,36

The parameters of brake pad applied at the present research (steel plate, friction material) were defined on the basis of previous results of J. Choi et al and A. Belhocine et al.[2] [6]. Table 2. shows the parameters of steel plate and friction material.

2. Table: Properties of brake material

	Young modulus [GPa]	Poisson Ratio
Friction material	1	0,25
Steel plate	210	0,3

Different piston materials and design were compared with finite element software, where temperature's effects were ignored. At staring the piston behaviour was defined in simplified model. 2D axisymmetric model was used in Ansys Workbench 11 software. The model consists of piston and brake pad, which is shown in Figure 1/a. Piston's diameter is 44 mm (Radius is 22 mm) and height is 29 mm. For each material the deformation was determined where wall thickness changed between 0.5 mm and solid (full version) pistons. Brake pad has two parts. One of them is the steel plate dispersing pressure of piston. Other part is the friction material sliding on the disc during brake operation. First, geometry was defined then all parts were meshed, quadrilateral element was used where the least element size is 0.01 mm and the biggest element size is 0.3 mm (Fig. 1/b). Element's number depends on the construction. Number of elements increase when wall thickness is getting bigger. When the wall thickness is 0.5 mm, number of element are 6305 (nodes: 19670) and if piston is solid, number of elements are 11940 (nodes: 36623)
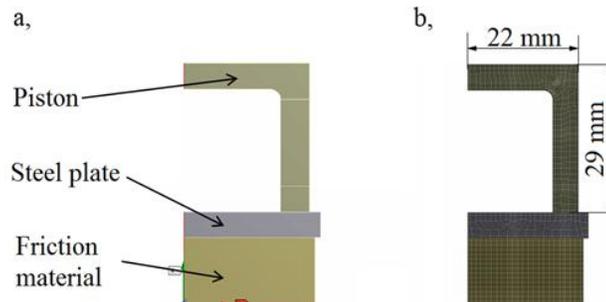
Figure 1. a, 2D axisymmetric model (piston, brake pad); b meshed model

Further in this study two cases were examined. In first case the seal ring is in the caliper (SIC), where brake fluid press piston's face and piston's side (Fig. 2/a). In second case seal ring is in piston (SIP), in this case the brake fluid press only piston's face (Fig. 2/b).
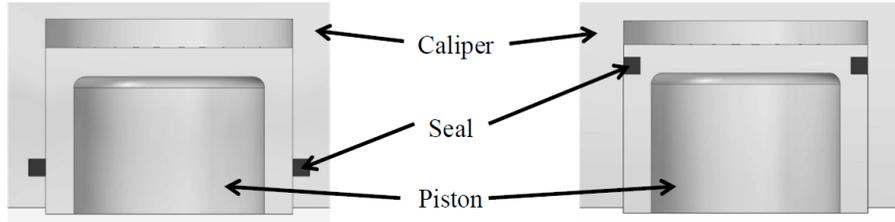
Figure 2. Seal ring position: a, Seal ring in caliper (SIC), b, seal ring in piston (SIP)

External constraints and loads were defined (Fig. 3). Model was 2D axisymmetric so displacement of central axis was 0 in X direction; movement in Y direction is free. Displacement of brake pad's friction surface was 0 in Y direction and in X direction is free. Pressure in this study is 15 MPa. It means that safety factor is 3, because emergency braking is considered about 5 MPa. The contact between the parts was determined. Connection between friction material and steel plate is bonded, which models the reality. Frictional contact was used between steel plate and piston having friction coefficient 0.1.
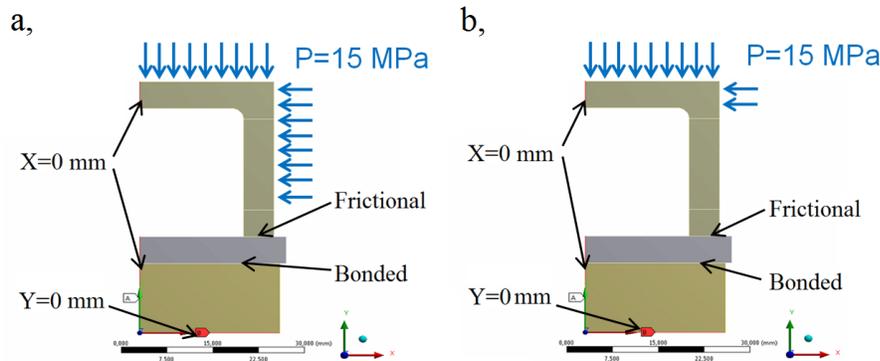
Figure 3. External constraints in X and Y direction, loads (safety factor is 3) and connection between parts (bonded, friction connection) a, seal in caliper (SIC) b, seal in piston (SIP)

3   RESULT

One of the most important aspects of the study is the stress, so stress distribution in the piston was determined. Stress was changed by wall thickness; maximal stress of piston can be seen in Figure 5. The already mentioned two constructions were examined. Figure 4/a shows maximal stress values in case of in different piston materials, where seal ring is in caliper. Figure 4/b shows maximal stress, where seal ring in piston.
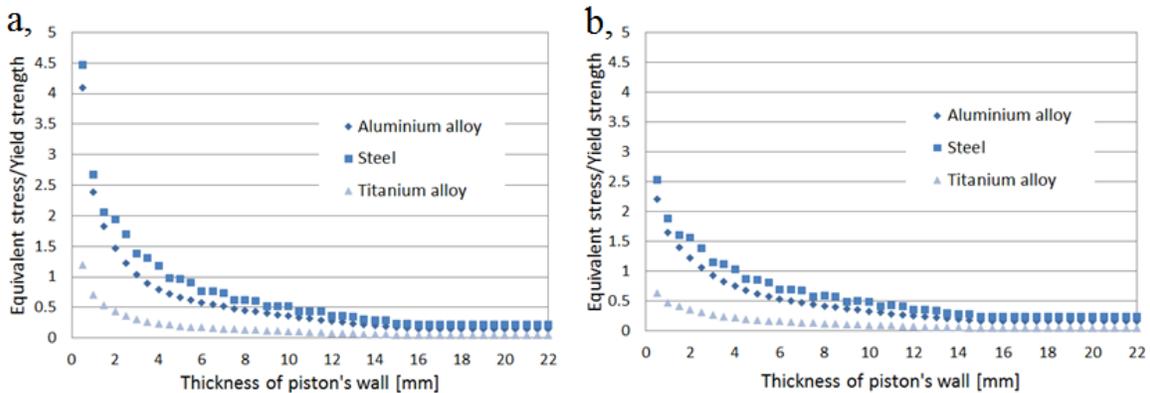
Figure 4. Maximum stresses in piston: a, Seal in caliper (SIC); b, Seal in piston (SIP)

The other main aspect is piston's deformation, which was determined in finite element software. Deformation was examined in the introduced two cases: first case seal ring is in caliper, where brake fluid presses piston's side and face. Second case is where seal ring is in piston and brake fluid presses piston's face. To get to know the piston's deformation is important (Fig. 5), because in some cases the deformed shape can lead not proper functioning or sticking of piston in caliper.
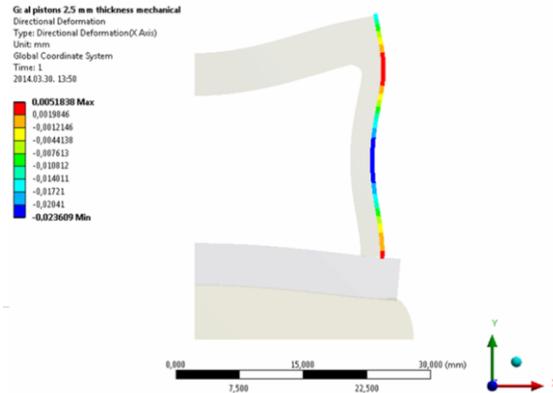
Figure 5. Piston's wall deformation, when wall thickness is 2,5 mm (5X)

Figure 6 shows the piston's wall deformation in function of wall thickness. Figure 6/a shows the deformation where seal ring is in caliper (SIC). In both cases when wall thicknesses are small the deformation is big. In this case (Figure 6/a) the direction of wall's deformation shows into pistons center, because brake fluid presses piston's side. If the wall thickness is increased, deformation decreases. Figure 6/b shows the deformation when seal ring is in the pistons (SIP). At this construction the direction of the deformation is opposite, because brake does not press the piston's side. That predicts decreasing clearance between the caliper and piston. In case of solid piston (which means the possible maximum mass of piston) the deformation is negligible.
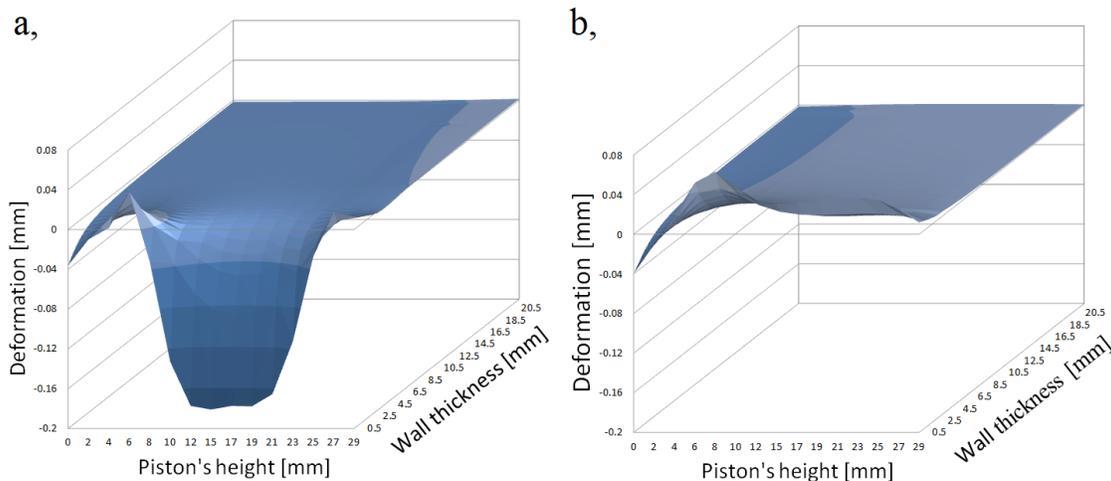
Figure 6. a, wall's deformation when seal ring is in caliper (SIC); b, wall's deformation when seal ring is in piston (SIP)

4   DISSCUSSION

Beside the given material and wall thickness of the piston the seal ring position influences the stress distribution and way of deformation. The result show that the deformation is different in the mentioned two cases (SIC, SIP) Stress level was found double when seal ring is in piston compared to seal ring in

caliper. When piston's wall thickness increases, stress distribution gets more even in piston. Figure 7 shows piston's stress having different materials.
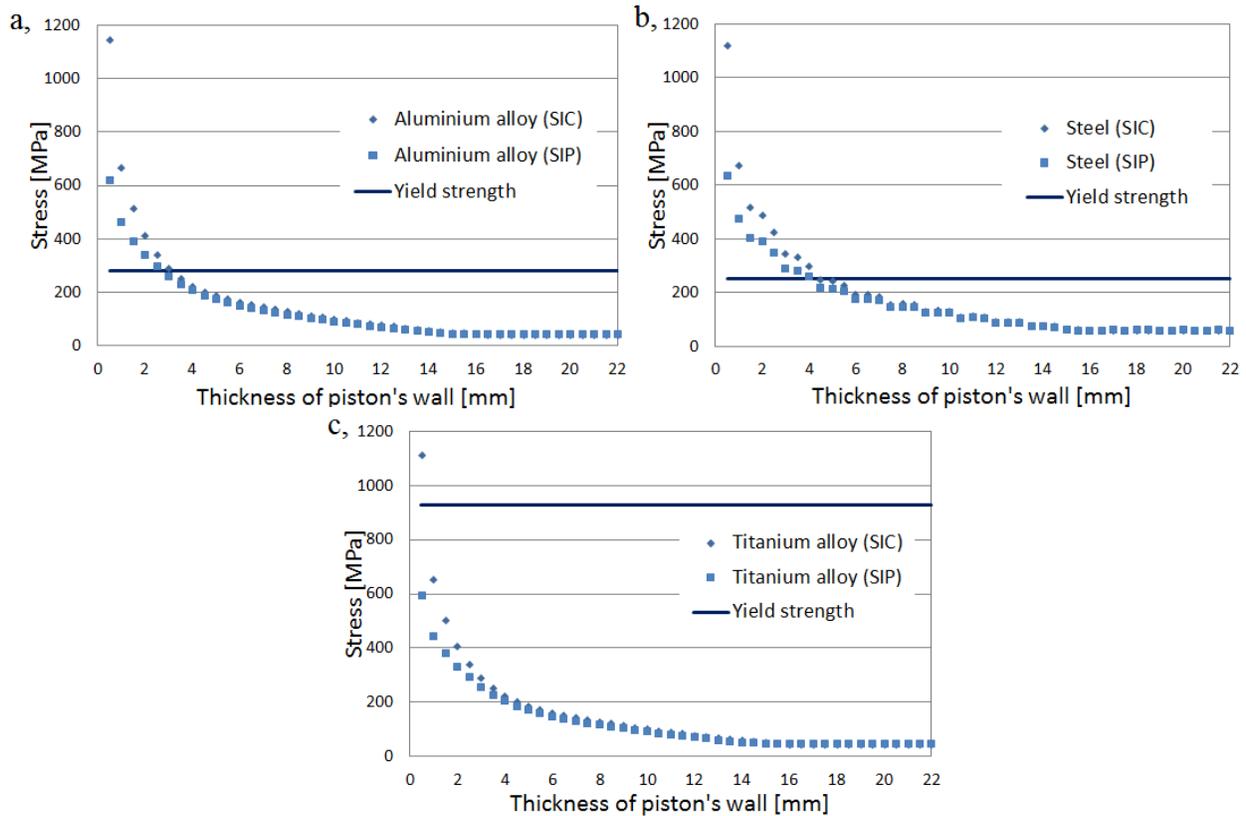
Figure 7. a, maximum stress in aluminium alloy (a), steel (b), titanium alloy (c) piston in the function of wall thickness

This figure shows the materials's yield stress, too, with a horizontal line, so the arising stresses in the function of wall thicknesses can be evaluated from the point of elastic or plastic behaviour as well. When piston's wall thickness is getting bigger, the stress becomes similar in both case (SIC, SIP). Having low wall thickness the arising stresses exceed the material's yield strength almost in all cases. When aluminium alloy (3.4335) was used the necessary minimum wall thickness (reaching the yield stress level) is 3.12 mm (σ=280 MPa), when seal ring is in caliper. In case of seal ring is in piston the necessary wall thickness is 2.69 mm (σ=280 MPa). For steel piston material (1.0039) the necessary minimum wall thickness is 4,66 mm having 251 MPa stress, when the seal ring is in caliper. In other construction (seal ring in piston) 4.02 mm wall thickness was necessary (σ=251 MPa). For Titanium alloy piston the minimum thickness was found 0.63 mm with 930 MPa when the seal ring is in caliper. In the second construction the necessary wall thickness is only 0.17 mm theoretically beside 930 MPa stress. In these cases the stress is just not exceed the yield strength.

The examined other parameter is deformation of the wall of piston, which is important after setting the necessary minimal wall thicknesses. The allowed deformation depends on the tolerances and clearance between the piston and caliper. Normally the clearance in these constructions is about 0.04 mm between the two parts [5], meaning H7/g6 dimension settings used. Taking 0.04 clearance mm between caliper and piston means a gap in side 0.02 mm, which can be considered as the maximum allowed deformation of the piston's wall. Figure 8/a shows the allowed deformation when seal ring is in caliper. For aluminium alloy piston the wall thickness is 1.18 mm with deformation 0.02 mm. The same deformation means 0.14 mm necessary wall thickness made of steel. For Titanium alloy piston's that is 0.8 mm. So in these border dimensions the arising deformation is predicted under the critical 0.02 mm gap. In the other case, when the seal is in pistons (Fig 8/b), the wall thickness is 2.51 mm (def=0.02 mm) for aluminuim piston. For steel case it is 0.58 mm (def=0.02 mm) and 1.93 mm (def=0.02 mm) for titanium alloy piston.

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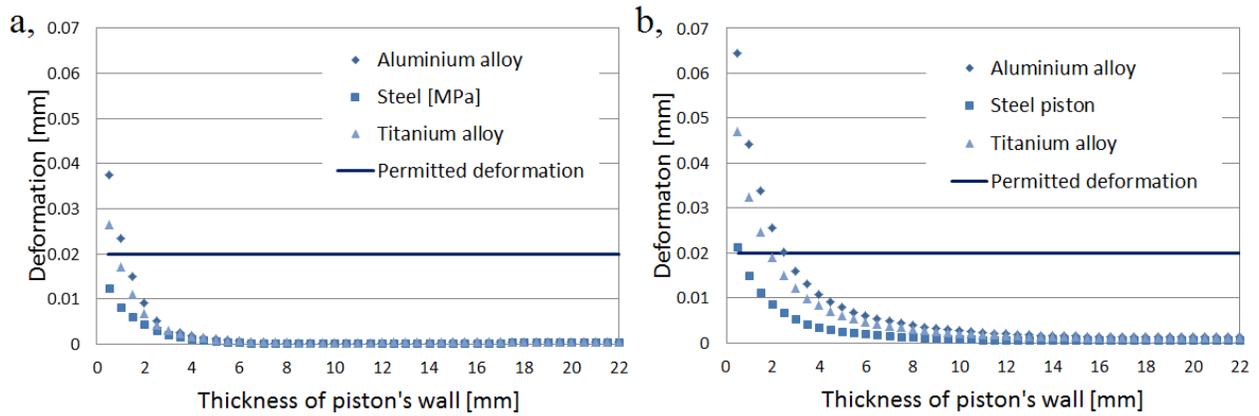
Figure 8. Deformation of piston when seal ring in caliper (a), and seal ring in piston; (b) allowed deformation is 0.02 mm

Figure 9/ a shows optimal wall thickness in function of stress in both constructions and Figure. 9/b plots the optimal wall thickness according to the allowed deformation is 0.04 mm (per side is 0.02 mm).
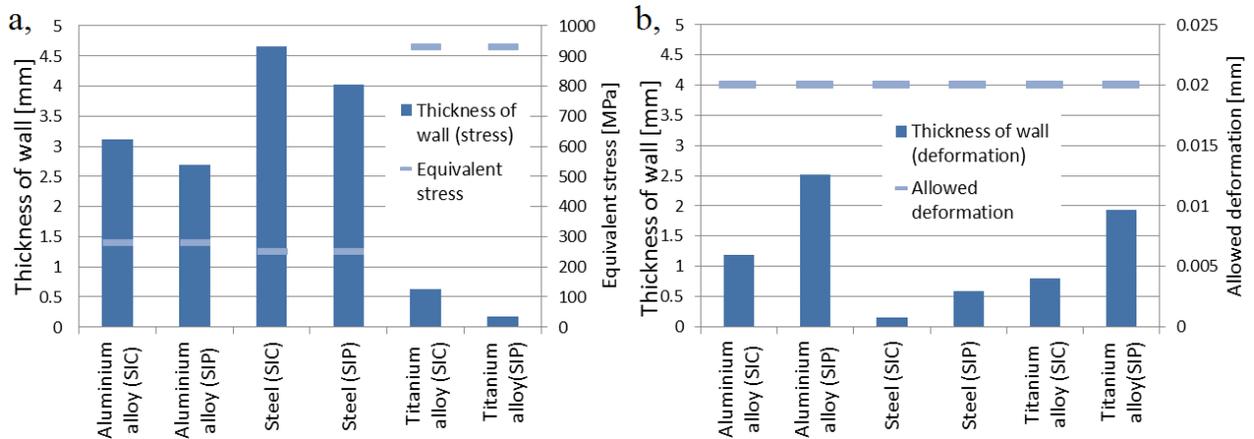
Figure 9. a, necessary wall thickness as a function of stress; b, necessary wall thickness as a function of deformation (Seal in caliper SIC, Seal in piston SIP)

On Figure 10. the deformation and stress results are side by side. Easy to compare the results to state which parameter determines the optimal wall thickness. In most cases the stress parameter defines the necessary minimal (and considered optimal) wall thickness. Steel piston performed essential difference between stress and deformation parameters. When titanium alloy was used, the deformations capability was found the critical parameter.
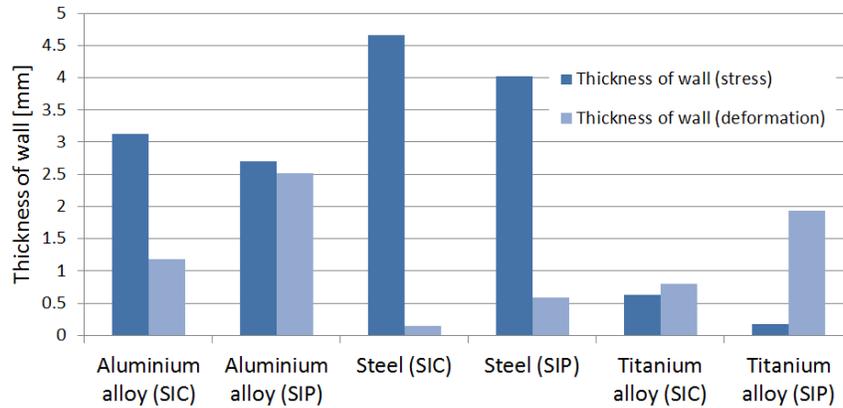
Figure 10. Optimal wall thickness in all cases

Table 3. shows optimal wall thicknesses in different cases. This table includes material and seal ring position.

Table 3. Optimal construction in different cases

	Seal in caliper (SIC)	Seal in piston (SIP)
Aluminium alloy (3.4335)	3.12 mm	2.69 mm
Steel (1.0039)	4.66 mm	4.02 mm
Titan alloy (3.7165)	0.8 mm	1.93 mm

The unsprung mass is important in brake system, so weights were defined according to the optimal wall thicknesses (Figure 11.)
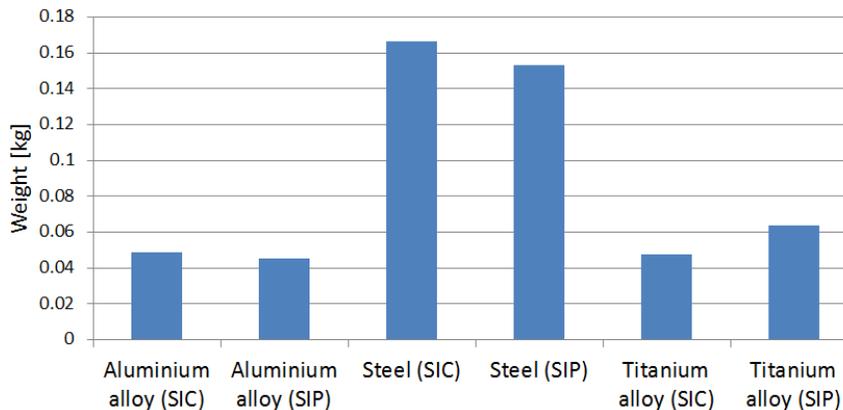
Figure 11. The calculated piston weights

Steel piston is the heaviest (seal ring is in caliper: 0.153 kg, seal ring is in piston: 0.163 kg). Aluminium alloy and titanium alloy piston's weight is similar. Titanium alloy piston's weight is 0.047 kg when seal ring is in caliper and when seal ring is in piston weight is 0.064 kg. Aluminium alloy piston gives the lightest weight (seal ring is in caliper: 0.048 kg, seal ring is in piston: 0.0045 kg). These results show that optimal construction can be made with aluminium alloy piston, where the seal is in the piston. The stress is under 280 MPa (yield strength) and deformation is under 0.02 mm critical value. This construction is suitable up to working load 15 MPa.

5   CONCLUSION

Deceleration of the vehicles depends on the construction of brake and the efficiency of the whole break system. Many studies examine disc brake, drum brake, measure different material's friction coefficient to

define the best materials, where friction coefficient does not change. In these studies piston's influence is not examined or simple model was used.

Piston's role during brake operation is important, because the piston presses the brake pad to the disc and the piston's geometrical layout influences the pressure distribution. Inadequate piston can result low performance and efficiency, or in critical case, the brake system does not work anymore.

At present research the piston's outside diameter is 22 mm and height is 29 mm. Aluminium alloy (3.4335), steel (1.0039), titanium alloy (3.7165) piston materials were examined with FEM where seal ring of piston has two positions. At first case the seal ring is in caliper and other case the seal ring is in piston. The calculated results show big difference between the two cases applying small wall thicknesses of piston. The difference disappeared when wall the thickness were higher or solid piston was used. The study determined the optimal construction analysing the stress, deformation and weight values of piston.

When aluminium alloy piston is used the optimal piston has 2.69 mm wall thickness and seal ring is in the piston. The arising stress is 280 MPa (yield strength) and maximum deformation is 0.02 mm.

In case of steel piston the best construction has 4.02 mm wall thickness and seal ring is in piston, too, and the stress is 251 MPa (yield strength) beside deformation 0.02 mm.

When titanium alloy piston was used the best construction is 0.8 mm wall thickness and seal ring is in piston. the stress is 785.42 MPa and the maximum deformation is 0.02 mm (allowed deformation).

Furthermore the weights were defined. The aluminium alloy piston's weight is 0.045 kg, steel piston's weight is 0.153 kg, titanium alloy piston's weight is 0.047 kg. The weight of brake system including the piston as well, affects the unsprung mass, which influences the the vehicles controlling. Based on the present research the aluminium alloy piston was found the best, having optimal wall thickness 3 mm.

6   REFERENCES

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