Lightweight innovative composite dry clutch pressure plate

T Cakmak1*, Z Cagatay Oter2, O Surmen3

1 Valeo Automotive Industry and Trade Co., Bursa, Turkey
2,3 FSMVU, Aluminum Test Training and Research Center, Istanbul, Turkey

*Corresponding author: tolga.cakmak@valeo.com

Abstract. This study presents an innovative lightweight composite dry clutch pressure plate including aluminum foam structure in its core. Mechanical burst performance via finite element method of five different composite designs, in which the core foam structure is planned to be obtained via powder metallurgy, is considered. Moreover, a literature review of the powder mixture effect on aluminum foaming experimentation is presented. Compared to conventional serial clutch pressure plate, proposed composite concept reduces the overall weight by up to 47%, however increases stress by up to 65%. Concept design does not only reduces the weight but also enhances the heat dissipation thanks to the increase of convective surface. Mechanisms in the present study are helpful to motivate further innovative lightweight solutions in order to overcome the challenges related to the recent CO2 regulation for Heavy Duty Vehicles.

1. Introduction

Transport sector is a very competitive market in which the main driving force is the weight reduction while the costs are maintained or reduced. Thus, only the lightweight solutions that are accomplished by a performance improvement are worthy to be developed. Trucks face several challenges: one is related to the recent CO2 regulation for Heavy Duty Vehicles (HDV). Moreover, fuel consumption is the most effective factor in the estimation of all direct and indirect costs associated with a 40t heavy duty truck over its six years or 110,000 km life cycle [1]. The European Union, United States, Canada, China, Japan and India already have HDV CO2 emissions or fuel consumption standards in place [2]. Figure 1 presents two important drivers and technological trends affecting powertrain of HDVs.

![Figure 1. (a) Total Cost of Ownership (TCO) [1] and (b) CO2 standards for Heavy Duty Vehicles [2].](image-url)
The heaviest part of the clutch system is the cast iron manufactured pressure plate. With the recent developments in transmission parts, increasing filtering capacity of the damper (disc assembly with lower stiffness) technology to reduce the vibrations of the gearbox offers also a substantial advantage in weight reduction potential of clutch technology. Thereof, even if the lightweight pressure plate is applied on a vehicle with noise, vibration and harshness (NVH) borderline performance, engineers today can easily overcome the degradation in engine acyclisms (due to the relatively lower inertia linked to the crankshaft) thanks to the new damper technologies.

On the other hand, clutches suffer from the consecutive and repetitive clutch engagements within fully loaded HDVs on roads with slope or with heavy traffic result in premature failure of these parts by thermal fatigue and excessive temperature rise. Convective heat transfer can be enhanced by increasing the convective heat transfer surface [3]. Clutch system ensures the comfort during gear change. During the engagement, generated heat flux is spread between opposing frictional parts; flywheel, pressure plate and disc facings (Figure 2). Repetitive and consecutive engagements can result many clutch failures due to temperature rise on the friction surfaces [4]. Consequently, the clutch transmission characteristic is affected negatively by the temperature rise [5]. It is also shown in the literature that one of the most effective clutch design parameter to prevent dramatic temperature rise is convection surface improvement of the pressure plate [6]. Similarly, the positive effect of convective cooling in brake discs has been demonstrated [7]. It has been also experimentally verified that the enhancement of cooling performance is feasible via implementation of ventilation channels into clutch pressure [8].

![Figure 2. Dry clutch system.](image)

The aim of this research is to reduce the weight of the clutch pressure plate thanks to aluminum foam structure in its core. Proposed concept design is also enhancing the convective heat transfer that is planned to be investigated in further studies. Thus, dramatic temperature rise during repetitive engagements will also be prevented. Five different versions are designed and compared with that of conventional design in terms of mechanical burst strength. In addition, innovative design results fuel consumption saving by weight reduction. Thus, proposed design would contribute to reduce automotive tailpipe CO$_2$ emissions.

2. Material and Method

In manual transmissions, there are several validations of new designs including thermal and mechanical solicitations. Numerical or experimental validations or the bench test conditions are based on the operating conditions on the vehicles. The test conditions vary depending on the application; passenger car, heavy duty or tractors. One of the mechanical validation is to ensure that the clutch component is safe under maximum rotational speed within the operating range. In this work mechanical burst performance representing rotational speed safety via finite element method of five
different composite designs, in which the core foam structure is planned to be obtained via powder metallurgy, is considered.

2.1. Concept Designs and Numerical Analysis

Numerical simulation is computed by means of static structural finite element analysis. Stress variation of the aluminum-foamed versions is analyzed and compared with that of conventional serial case. Visuals of analyzed pressure plates for heavy duty truck applications are shown in Figure 3.

Geometric properties of the pressure plates are shown in Table 1. The conventional material choice of the pressure plate is gray or ductile cast iron due to its good surface finish, machinability, thermal capacity, wear resistance and low cost. In this study, composite structure including aluminum foam inside cast iron cavity is proposed. The sections those need to withstand high stress or requires machining remain cast iron. For example, the friction surface that is in contact with disc facings and the fulcrum section that is in contact with diaphragm spring. Both sections are also machined after casting process.

Additional to weight reduction, one of the aim of implementing the aluminum foam is to enhance the heat dissipation from the pressure plate by increasing the compactness ($m_1$) that states the ratio of the convection surface ($m_2$) to the volume ($m_3$). However it is not possible to estimate it due to the foam’s irregular surface. On the other hand, it is expected to have more convective surface compared to the solid one.

| Geo  | Casting Mass (kg) | Machined mass (kg) | External Diameter (mm) |
|------|------------------|--------------------|------------------------|
| Serial | 28.00            | 25.20              | 430                    |
| (1)   | 16.80            | 14.30              | 430                    |
| (2)   | 17.00            | 14.50              | 430                    |
| (3)   | 15.90            | 13.40              | 430                    |
| (4)   | 15.60            | 13.00              | 430                    |
| (5)   | 18.00            | 15.50              | 430                    |

In the previous numerical models, pressure plate 3D full model had been analyzed [3,9]. In this work, quarter model of the clutch pressure plate is considered (Figure 4). This approach enables faster computation compared to previous models. Numerical model and boundary conditions are shown in Figure 4.

- Cyclic region on the symmetry faces.
- Rotational velocity for both cast iron and aluminum foam bodies.
- Bonded contact between cast iron and aluminum foam contact surfaces.
- Radial displacement is free at ear hole.
- Cast iron and crushable aluminum foam material is assigned to the models.
2.2. Powder Metallurgy Method for Aluminum Foam Production

Among the liquid processing techniques for aluminum foam processing, the powder metallurgy (PM) method is preferred because the net shape final parts can be produced [10,11]. The PM process is carried out in three main steps; The first step is to mix pure or pre-alloyed aluminum powders with a foaming agent (usually TiH\(_2\)). In the second step, the powder mixture is compressed by techniques such as cold / hot pressing or extrusion to obtain a high density semi-product. In this study, this semi-product was called pellet. Finally, the pellets are heated above the liquidus temperature of pure aluminum or aluminum alloy. At this stage, the gas pressure resulting from the decomposition reaction of the foaming agent and after rapid solidification forms a very porous semi-solid material. By cooling this semi-solid material to room temperature, foam material is produced [12,13].

A detailed literature research was carried out to determine the components and composition of the powder mixture to be used in this study. Composition of the powder is important because the interaction of the foaming agent and the matrix powder identify the physical and mechanical properties of the foam. The foaming agent used in the PM method should not react with aluminum. In addition, the temperature range at which the foaming agent decomposes (the gas that causes foam production is released) should be close to the semi-solid region of the alloy. In practice, the decomposition of the foaming agent at low temperatures causes the foams to lose their homogeneity

---

**Figure 4.** Numerical Model and Boundary Conditions – (Ansys R19.2).

The mesh structure for the computations is shown in Figure 5. The mesh model consist total 14356 tetrahedron elements and 26187 nodes for geometry 3. Mesh refinement effect on the results is also investigated and it is demonstrated in Section 3.1.

**Figure 5.** 3D Mesh Structure of the Numerical Model – Geo 3  
(a) view from inner diameter, (b) view from external diameter.
and prevent reproducibility [14]. Metallic hydrides such as TiH₂, ZrH₂ and MgH₂ [15] and carbonates such as MgCO₃ [16] and CaCO₃ [17,18] are used in the production of metal foams. Figure 6 shows the structures and decomposition reactions of different foaming agents.

| Foaming agent | Average particle size, d/μm | Gas | Chemical reaction |
|---------------|-----------------------------|-----|------------------|
| Titanium hydride | TiH₂ | 26 | H₂ | TiH₂ = Ti + H₂ |
| Magnesium hydroxide | Mg(OH)₂ | 7.4 | H₂O | Mg(OH)₂ = MgO + H₂O |
| Magnesium carbonate | Mg(OH)₂ | 11 | H₂O | 4MgCO₃·Mg(OH)₂·5H₂O = 4MgCO₃ + MgO + 6H₂O |
| Magnesium carbonate | MgCO₃ | 11 | CO₂ | MgCO₃ = MgO + CO₂ |
| Dolomite | CaMg(CO₃)₂ | — | CO₂ | CaMg(CO₃)₂ = CaCO₃ + MgO + CO₂ |
| Calcium carbonate | CaCO₃ | 13.5 | CO₂ | CaCO₃ = CaO + CO₂ |

Figure 6. Foaming agents [19].

Although it is expensive and relatively dangerous to handle, TiH₂ is the most popular foaming agent with a decomposition temperature that is close to the melting temperature of aluminum alloys [19,20]. It provides enough gas to form a high degree of porosity, even when used in very low amounts (~ 1%). However, increasing the amount of foaming agent further increases the amount of foaming. The amount of agent required to foam aluminum pellets in the production of foam metallurgy is 1-4%. In general, when the amount of foaming agent increases, foaming increases and the density of the foam decreases. Foam production temperature is also determined depending on the amount of foaming agent. Figure 7 and 8 shows the relationship between the amount of foaming agent and the efficiency of the foaming process. Figure 9 compares the foaming performances of different foaming agents.

Figure 7. Variation of the porosity depending on the amount of TiH₂ in aluminum [21].
As a result of the literature review and preliminary studies, it was decided to use TiH$_2$ powder as a foaming agent in pure aluminum. An experimental study will be designed to determine the optimum amount of foaming agent by means of performance and cost.

The main determinant in the choice of foaming agent is foaming performance. As it is understood from the literature research, many variables such as grain size, impurity and the amount of oxidation on the surface of the powder grains have a direct effect on the performance of the foam production process. For this reason, it is aimed to eliminate the variables that may arise from dust quality in prototype production studies and reach the most efficient foam production process. Since the powder consumption is not high in the prototype studies, laboratory quality TiH$_2$ powder is planned to be used as the foaming agent and pure aluminum powder will be used as the matrix. Powder mixture will be prepared using a ball mill. After the prototype studies are completed, a new feasibility study will be conducted and alternative matrix powders will be evaluated.

Figure 8. Structures of the foam samples produced at 670°C [22].

a) 0.5% TiH$_2$ b) 1% TiH$_2$ c) 1.5% TiH$_2$ d) 2% TiH$_2$

| 10mm | Cooling temperature | $\rho$ (g/cm$^3$) |
|------|---------------------|-------------------|
| TiH$_2$ 0.4mass% | 843K | 1.73 |
| Mg$_2$CO$_3$, Mg(OH)$_2$, 5H$_2$O 0.8mass% | 1.63 |
| MgCO$_3$ 0.8mass% | 1.89 |
| CaMg(CO$_3$)$_2$ 1.2mass% | 2.39 |

Figure 9. Performances of various foaming agents [19].
3. Results and Discussion

3.1. Validation of the Numerical Model

Numerical model is compared with a bench test result. Bench test aims to determine the mechanical strength of the clutch pressure plate under operating rotational speed. The bench test experimental work is performed at room temperature, and the reference speed of the centrifugation test depends on the external diameter of the friction surface, and constant acceleration is regulated by the bench. The criteria is not have cracks or breakage till reference speed.

Computation duration is 0.5 hour. On the other hand, experimental bench test duration including set-up is longer and more costly. Once the production period and cost is also taken into account the numerical approach provides a substantial advantage. In Figure 10, the comparison of the output of numerical method followed in this study and the result of experimental work is shown for the serial case.

![Figure 10. Comparison of Maximum Stress Vs Rotational speed – Numerical Vs Experimental.](image)

The comparison is presented only for the conventional serial pressure plate, since the real part is the only available one currently. The difference is around 10%, and reasons can be linked to the follows;
- CAD geometry that is not fully representative of the real part,
- The casting process that does not provide the same level microstructure at each location,
- The error in the tensile strength measurement (more samples could be needed) of the real part.

Grid independence is also verified by repeating computations with 4 times no of elements refinement of the initial mesh size. In Figure 11 comparison of maximum stress and maximum total deformation values of both analyses are demonstrated.
3.2. Burst performance evaluation of the lightweight composite designs

In Figure 13 mechanical burst performance comparison of serial and lightweight composite designs (Geo 1 – 5) are shown. Implementing aluminum foam into clutch pressure plate cavity results stress increase compared to serial case by up to 82%. Geo 1 demonstrates the worst (stress increase by 82%), Geo 5 presents the best (stress increase by 57%) mechanical burst performance among all concept designs. Compared to the conventional serial case, the change of stress and deformation values of composite versions are shown in Table 2. When the simulation error is considered, the results stay within the safety criteria for 275 MPa strength cast iron material.
Table 2. Compared to serial case the change of stress and total deformation values of composite versions at 5000 rpm.

| Geo | Machined Mass (kg) | Stress (MPa) | Deformation (mm) |
|-----|-------------------|--------------|------------------|
| Serial | Base | Base | Base |
| (1) | - 43% | + 82% | + 25% |
| (2) | - 42% | + 73% | + 17% |
| (3) | - 47% | + 65% | + 19% |
| (4) | - 48% | + 64% | + 17% |
| (5) | - 38% | + 57% | + 5% |

Maximum principal stress and maximum total deformation distribution at 5000 rpm of serial, Geo 3 and Geo 5 are shown in Figure 14 and Figure 15, respectively. The stress on aluminum foam is in acceptable range.

![Figure 14. Maximum Principal Stress (MPa) Distribution of the pressure plates, Serial (a), Geo 3 (b), and Geo 1 (c).](image-url)
4. Conclusion

The recent CO\textsubscript{2} regulation for HDVs pushes OEMs and automotive suppliers to find out the lightweight solutions that are accomplished by a performance improvement are worthy to be developed. For this purpose, in order to determine the mechanical burst performance of lightweight and composite clutch pressure plate, the numerical 3D structural simulation is presented. The simplified numerical model is cost effective and time saving. It is validated for conventional serial case but should be re-validated for composite cast iron-foam version. This study is limited to mechanical performance, can also be extended for the thermal performance in further studies.

Literature review of foaming experimentation via powder metallurgy is also presented and as a result it was decided to use TiH\textsubscript{2} powder as a foaming agent in pure aluminum.

5 different composite concept designs are investigated. Stress of the clutch pressure plate increases with the rotational speed. Aluminum foam implementation into cast iron clutch pressure plate provides weight reduction by upto 48\% but also results stress increase by upto 82\%. Moreover, even when the simulation error is considered, the results indicate that all proposed designs (Geo1-5) can meet the design criteria at 5000 rpm for 275 MPa strength cast iron material. Among investigated concept composite designs, compared to conventional serial case, Geo 3 presents the best compromise solution for stress and weight change by +65\% and -47\%, respectively. On the other hand, while compromising mechanical performance, composite structure presents better thermal performance with convection surface enhancement.

Importantly, our results provide evidence for the use of lightweight composite structures in clutch applications, that will support to achieve CO\textsubscript{2} emissions targets. Future research could examine the aluminum foaming application into clutch pressure plate, and thermo-mechanical performance tests of the lightweight composite pressure plate.

Acknowledgments

The authors gratefully acknowledge the support of Technology Research Council of Turkey (TUBITAK) (grant number 3190567).
References

[1] Nürk C and Maier M 2014 The Truck Market 2024, Sustainable Growth in Global Markets Deloitte 2014, Truck Study Report.

[2] ICCT 2019 CO₂ Standards for Heavy-Duty Vehicles in the European Union International Council on Clean Transportation.

[3] Kilic M, Cakmak T, Sevilgen G 2016 Clutch Pressure Plate Compactness Effect on the Clutch System Heat Dissipation 12th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics Spain Malaga pp 438-444.

[4] Abdullah OI, Schlattmann J, Al-Shabibi AM 2014 Thermo-mechanical Analysis of the Dry Clutches under Different Boundary Conditions Tribology in Industry 36 (2) pp 172-180.

[5] Pisaturo M 2013 Dry clutch for automated manual transmission University of Salerno, Mechanical Engineering Department Ph.D. Thesis.

[6] Cakmak T, Kilic M 2017 Clutch transient heat transfer simulation for hill start vehicle test condition 13th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics Slovenia Portoroz pp 698-702.

[7] Adamowicz A 2016 Effect of Convective Cooling on Temperature and Thermal Stresses in Disk during Repeated Intermittent Braking Journal of Friction and Wear, Fluid Mechanics and Thermodynamics 37 (2) pp 107-112.

[8] Cakmak T 2018 Taşıtlarda kullanılan debriyaj sistemlerinin termo-mekanik özelliklerinin iyileştirilmesi University of Uludag, Mechanical Engineering Department Ph.D. Thesis.

[9] Cakmak T, Sevilgen G, Kilic M 2018 Heat transfer enhancement in dry clutch pressure plate using ventilation channels 9th International Automotive Technologies Congress Bursa Turkey pp 1134-1140.

[10] Nosko M, Simančík F, Florek R 2010 Reproducibility of aluminum foam properties: Effect of precursor distribution on the structural anisotropy and the collapse stress and its dispersion Materials Science and Engineering: A 527 (21–22) pp 5900-5908.

[11] Hohlfeld J, Hannemann C, Vogel R, Hipke T, Neugebauer R 2011 Alternative starting materials for the production of aluminum foam by the powder metallurgical process Production Engineering 5 (1) pp 25–30.

[12] Stöbener K, Rausch G 2009 Aluminium foam–polymer composites: processing and characteristics Journal of Materials Science 44 (6) pp 1506–1511.

[13] Bonaccorsi L, Proverbio E, Raffaele N 2010 Effect of the interface bonding on the mechanical response of aluminum foam reinforced steel tubes, Journal of Materials Science 45 (6) pp 1514–1522.

[14] Lehmhus D and Busse M 2004 Potential new matrix alloys for production of PM aluminium foams Advanced Engineering Materials 6 (6) pp 391-396.

[15] Zeppelin F, Hircher M, Stanzick H, Banhart J 2003 Desorption of hydrogen from blowing agents used for foaming metals Composites Science and Technology 63 (16) pp 2293-2300.

[16] Park C, Nutt S R 2000 PM synthesis and properties of steel foams Materials Science and Engineering: A 288 (1) 31 pp 111-118.

[17] Gergely V, Curran DC, Clyne TW 2003 The FOAMCARP process: foaming of aluminium MMCs by the chalk-aluminium reaction in precursors Composites Science and Technology 63 (16) pp 2301-2310.

[18] Cambroneroa LEG, Ruiz-Romana JM, Corpsa FA, Ruiz Prieto JM 2009 Manufacturing of Al–Mg–Si alloy foam using calcium carbonate as foaming agent Journal of Materials Processing Technology 209 (4) pp 1803-1809.

[19] Koizumi T, Kido K, Kita K, Mikado K, Gnyloškurenko S, Nakamura T 2011 Foaming Agents for Powder Metallurgy Production of Aluminum Foam Materials Transactions 52 (4) pp. 728-733.

[20] Bhosle V, Baburaj EG, Miranova M, Salama K 2003 Dehydrogenation of TiH₂, Materials Science and Engineering: A 356 (1–2) pp 190-199.
[21] Yang CC and Nakae H 2000 Foaming characteristics control during production of aluminum alloy foam *Journal of Alloys and Compounds* **313** pp 188–191.

[22] Türker M 2009 Toz metallerji yöntemi ile alüminyum köpük üretimi 5. Uluslararası İlери Teknolojiler Sempozyumu (IATS’09) Karabük Türkiye.