# Novel Sample Creation Methods and Mechanical Modeling of Dry Friction Fibre Reinforced Hybrid Composite Clutch Facings

***Roland Biczó[1,*], Gábor Kalácska[2]***

**Abstract:** *Fibre pull-out among other dangerous failure modes and flammability of modern fibre reinforced hybrid composite dry friction clutch facing materials were considered to examine suitable sample creation methods for such complex and sensitive materials with mechanical material property identifications in mind. Abrasive water jet machining was found to have the smallest mechanical property modifying effect even if moisture levels caused by the method itself are considered. Tensile test according to DIN 53455 has been carried out on test samples cut with 1515 MAXIEM OMAX water jet machine and sorted into three different groups based on their moisture level: moist, dried, and untreated categories. Force-displacement curves prove that the method doesn't modify the mechanical properties of the samples cut from the fibre reinforced hybrid composite dry friction facings: maximum forces vary among values between 1600 – 2000 N at about 0,7 mm displacement. Samples then are created to examine mechanical material properties of the hybrid composite separately for the fibre reinforcement and the matrix (a short fibre reinforced composite itself) component groups based on the rule of separation, since some elements of the matrix are part of industrial secret. Tensile test, Iosipescu shear test and two directional strain measurements are carried out accordingly for Young's modulus, shear modulus and Poisson's ratio respectively. Stiffness matrices created this way are then united in a stiffness tensor of a quasi-laminate via the rule of mixtures. Tough the list of phenomena taken into consideration by this modeling method lacks fibre-fibre adhesion or fibre-matrix adhesion, abrasive water jet cutting is then utilized for thermal property investigation sample and pin-on-disc tribological specimen creation.*

**Keywords:** *hybrid composite, stiffness matrix, water jet cutting, clutch facing*

## 1 INTRODUCTION

Characterization and modeling of modern fibre reinforced hybrid composites is essential for successful dry friction clutch development. This kind of material is an optimal response to the ever-growing requirements of friction materials in conventional and modern transmission systems. A peak not only of structural, but also material design effort since 1886, the year the Benz Motorcar was introduced with belt transmission. Today such friction materials are used in conventional passenger cars, heavy duty vehicles and hybrid applications as well.

In order to locate this special material in the transmission systems Figure 1. provides illustrated examples: the clutch disc itself delivers torque from flywheel to transmission via friction while the contact is created by the axial force from the pressure plate.

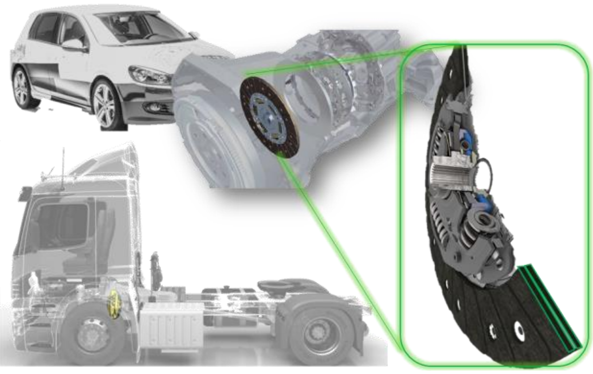

*Fig. 1. Location of the automotive clutch disc and its friction material in different applications*

Such a contact has many aspects: besides thermal and mechanical, tribological features should also be taken into account as well.

As a result, investigations and researches regarding this material usually circle around three main topics: mechanical properties, thermal phenomena and tribology with the requirements, loads and operating conditions in mind. [3]

From mechanical aspect in fibre reinforced materials adhesion between fiber and matrix and its governing parameters along with fiber–fiber friction conditions are among the most important fields in which researches are done. Besides that, influence of production process parameters on warpage, shrinkage, and residual stress are important. among others Zarrelli et al. [9] highlighted that selecting manufacturing parameters wisely can effectively reduce cost and prevents problems additional problems as well such as micro cracks, and fiber–matrix failures.

On the other hand, thermal topics mainly focus on hotspots – small areas of high temperature and pressure, thermo-elastic instability, shrinkage induced by curing process, or third body phenomena in thermo-mechanical contact. Ahn and Jang [1] carried out a two-dimensional contact problem-solving transient finite element simulation revealing the change in hotspot location via a thermo-elastoplastic instability (TEPI) after cooling.

Effects of components and manufacturing parameters on frictional properties are usually revealed in tribological scholars. Pin-on-disc test set-ups for instance turned out to be effective tools to observe Friction coefficient and wear. Fernandes et al. [4] found that the stability of multi-layer friction films can be influenced by sliding conditions and that removing wear debris results in increasing friction level and reducing wear rates.

Mechanical, thermal, tribological – all fields of research require test specimens machined from the exact same part going under investigation. What is more these samples must have unchanged material properties compared to the whole part they are cut from. Besides that, small friction areas are needed for most tribological tests. To achieve those, accurate and careful machining is required controlled by a reliable system

While characterizing a material from all aspects requires many experiments. Additionally, the more experiments are to be carried out the more different samples and specimens are to be created.

## 2 SAMPLE CREATION

Dealing with fibre reinforced composites certain failure modes should be taken into account before sample creation. Fiber pull-out is one of them standing for the damage in adhesion between the fibers and the matrix. Some machining methods, such as sawing, etching etc. could result in fibers pulled out of the matrix. As a consequence, the test piece becomes mechanically modified being unable to model the behaviour of the part it has been cut out from. Flammability on the other hand rules out the utilization of laser cutting, despite its advantages considering precise contours.

To avoid all these unwanted consequences water jet machining provides a solution. Being amongst the novel machining techniques used in many industrial applications this non-conventional machining process removes material by impact erosion of high-pressure high velocity of water and entrained high velocity of grit abrasives on a work piece [7] as illustrated in Figure 2.

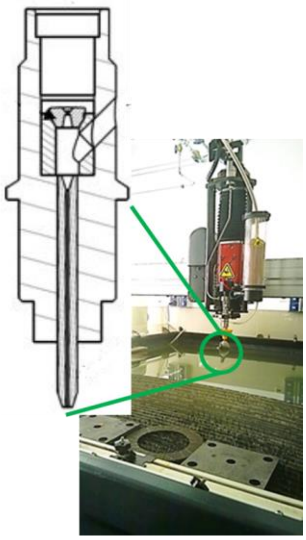

*Fig. 2. Abrasive water jet machine setup*

Advantages of machining with abrasive waterjets over other technologies are: no heat generated in the work piece, low machining forces induced on the workpiece, possibility to machine a wide range of materials and free contouring possibilities without the need of material or geometry specific tools. [5] Pre and post manufacturing of polymer material properties were examined and compared by Ramulu and Arola to find that water jetting parameters and setup values of the technic has an effect on the final topology and mechanical properties. [6] Aberdi et al concluded, that manufacturability and the effects are dependent on the machined material. [2]

However, when water – the transfer medium of this technique – is observed to have gotten into the environemnt of a dry friction fibre reinforced clutch material it usually causes functional issues. For instance inappropriate storing can lead to wetting effecting shape and dimensions. Humidity in the transmission system – morning startup of vehicles parked outdoors – is responsible for mating of uneven surfaces creating unwanted vibration, the cold judder: This phenomena certainly modifies the frictional and mechanical parameters of the clutch facings

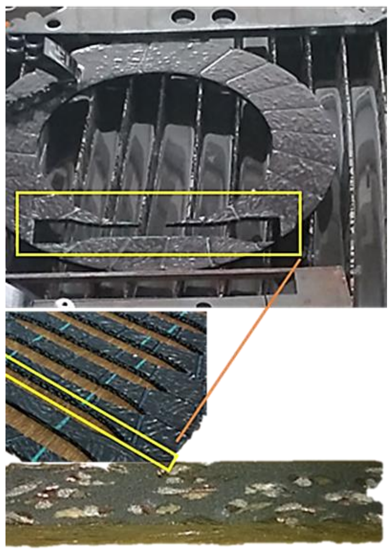

*Fig. 3. Specimen creation via abrasive water jet cutting from the clutch facing*

Therefore the applicability of samples created via water jut machining – as illustrated in Figure 3. – is tested through a tensile test that is performed according to DIN 53455. Samples created by 1515 MAXIEM OMAX abrasive water jet cutting machine are sorted into three groups based on their moisture levels: Group 1 samples went under a slight heat treatment, drying (15 minutes, 150 °C), to give results of specimens left long untouched. Group 2 samples were placed between moist layers for 15 minutes. Group 3 remained untreated after cutting.

The stress – displacements curves of three test samples with different moisture levels can be seen on Figure 4. However, no significant difference can be detected. Results are indicating no harmed structure. Therefore, water jet cutting has not modified the material properties of the dry fiction clutch facing.

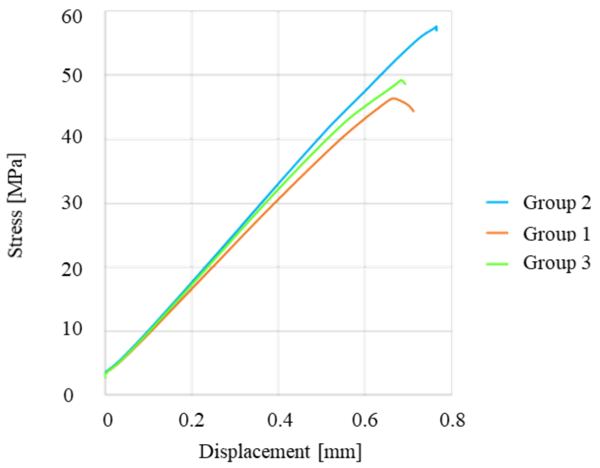


*Fig. 4. Abrasive water jet machine setup*

To conclude, abrasive water jet machining turned out to be a useful method for creation of test specimens for dry friction hybrid composite facing mechanical and tribological investigations in order to characterize the material and its contact behaviour.

## 3 CHARACTERIZATION

Characterization of complex dry friction clutch facing materials is essential in order to effectively support material and design development. Dry friction fibre reinforced hybrid composite clutch facings are produced so, that until fibre reinforcement and matrix are joined together by coating the so-called yarn, the woven braid of long fibre reinforcement, they are handled separately. Half the production line is responsible for yarn creation, the other half produces extruded coating from short fibre reinforced granulate.

### *3.1 Separation and ROM*

Therefore, the hybrid composite is divided into two component groups. The first group is long fibre reinforcement This component group consists of glass fibre, copper, aromatic polyamide and poly-acryl-nitrile. The second group, the matrix, being a hybrid composite itself as well containing short fibre reinforcement, fillers, sulfur, phenol and melamine resin etc. Industrially secret component properties and special orientation due to wreath-waving production method are challenges to face during the characterization of this material. Therefore, the idea of separation provides opportunity to determine the mechanical properties of these two component groups separately, followed by the utilization of a rule of mixture (ROM) in order to create a mechanical stiffness matrix.

Among others, ROM is utilized in micromechanical models like Tsai-Pagano [8] model created for randomly oriented fibrous composites. The main idea is to deal separately with fiber and matrix properties then unite them to evaluate mechanical properties of the whole composite. The Tsai-Pagano equations are:

$$E_{11}^* = E_m * V_m + E_f * V_f\,, \qquad (1)$$

$$E_{22}^* = \frac{E_f * E_m}{E_f - \sqrt{V_f}(E_f - E_m)}, \qquad (2)$$

$$E = \frac{3}{8}E_{11}^* + \frac{5}{8}E_{22}^*\,, \qquad (3)$$

$$G = \frac{1}{8}E_{11}^* + \frac{1}{4}E_{22}^* \qquad (4)$$

$$\nu = \frac{E}{2G} - 1, \qquad (5)$$

where:

- $E_m$; $V_m$ – elastic modulus and volume of the matrix component group,
- $E_f$; $V_f$ – elastic modulus and volume of the long fibre reinforcement component group,
- $E_{11}^*$ – fictive elastic modulus in the direction of load,
- $E_{22}^*$ – fictive elastic modulus perpendicular to the direction of load,
- E – effective elastic modulus,
- G – effective shear modulus,
- υ – effective Poisson’s ratio.

Considering the ever-growing expectations against dry friction facing materials, the method developed for material characterization is required to be flexible to be able to respond quickly when effects of novel components are to be examined or requirements change so, that redefining of tolerances is needed.

### *3.2 Measurements*

Properties of the ‘matrix component group’ were evaluated through measurements on facings made only of coating matrix produced without long fibre reinforcement though receiving hot pressing and curing.

A side-examination was also carried out to compare effects of extrusion production steps. Facings created via processes with and without this specific step were compared by tensile strength revealing that extrusion increases the value of this mechanical material property. It can also be concluded, that the matrix itself is indeed a composite with short fibre reinforcement – hence the hybrid composite name.

Via abrasive water jet cutting test specimens were created from these facings. Figure 5 illustrates the necessary measurements for the characterization of this component group:

- tensile test according to DIN 53455 to evaluate tensile strength,
- two directional strain measurement to determine Poisson’s ratio ,
- and Iosipescu shear test for characterising shear modulus of the matrix.

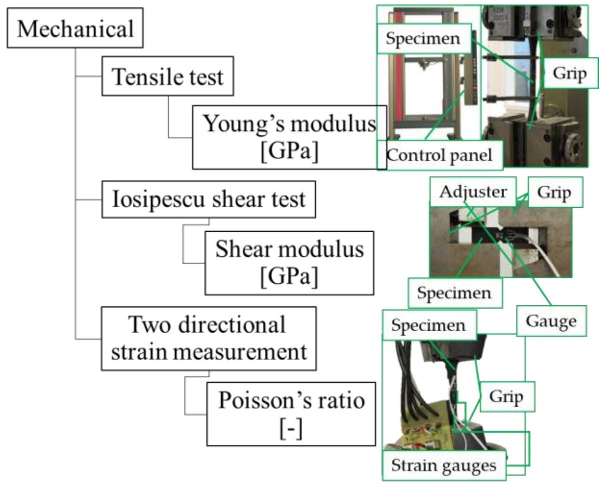


*Fig. 5. Measurements for mechanical characterization of the matrix component group*

In order to evaluate the mechanical properties of long fibre reinforcement component group, standard, so-called quality tests of facing material production were utilized. From the different long fibre properties, the lowest fibre Poisson ratio was taken into account.

### *3.3 Uniting results*

Considering the fact, that if the reinforcement was parallel to the loads the elements of the stiffness matrix would be generated via Equations (1) – (5). However, those results are to be transformed into a cylindrical coordinate system taken the fact into account, that fibres are positioned in 47° to the direction of the radial coordinate direction. Creating a quasi-laminate, the properties of the whole facing are detailed in Table 1:

*Table 1. Mechanical properties of the dry friction facing material of the clutch*

| | | |
|---|---|---|
| $E_{11}; E_{22}$ | [Gpa] | 12.3 |
| $E_{33}$ | [Gpa] | 4.3 |
| $\nu_{12}$ | | 0.46 |
| $\nu_{23}; \nu_{13}$ | | 0.38 |
| $G_{12}$ | [Gpa] | 7.6 |
| $G_{23}; G_{13}$ | [Gpa] | 1.3 |

## 4 CONCLUSIONS

Today's fibre reinforced hybrid composite clutch facings are the responses of century long material and design development regarding automotive clutches. Growing expectations and challenges drive researchers to create novel methods for characterization and model behaviour. In this study an effective way to create mechanical material models for such complex materials is provided presented via a specific example. The method however is flexible enough to support all conventional and modern automotive dry friction clutch areas: trucks, transportation vehicles and hybrids as well.

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**Authors addresses**

[1] *Roland, Biczó, PhD Student, Institute of Technology, MATE, Páter Károly u. 1., H-2100 Gödöllő, Hungary; rolbicz@gmail.com*

[2] *Gábor, Kálácska, DSc, professor, Institute of Technology, MATE, Páter Károly u. 1., H-2100 Gödöllő, Hungary; kalacska.gabor@uni-mate.hu*

**Contact person**

** *Roland Biczó, PhD Student,* rolbicz@gmail.com