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Effect of Sliding Speed on the Thermal Fields and Frictional Behaviours of Asbestos-free Frictional Materials Used for Dry Clutch System

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Abstract. Friction materials are utilized in systems that require explicit contact interaction between at least two components. The requirement to obtain successful frictions materials (high resistance for thermal and wear) is very difficult to such an extent that the market for friction devices is about seven billion dollars for each year. Common applications of the friction materials are automotive clutches and brakes systems where frictional materials play a significant role in these systems. In clutch systems, the tribological contact under sliding condition during the engagement maneuver is strongly affected by the frictional heat generated occurring in the system. Owing to the sliding between the contacting parts, this will lead to produce the mechanical energy losses, which are converted in heat with ensuing temperature increase. The magnitude of temperature rise depends on the complex interaction between frictional characteristics of materials, contact pressure, sliding speed, thermal properties of contacting materials. During the early stage of engagement of friction clutch, high energy is dissipated due to slipping between the contact surfaces. Hence, the surface temperature of the clutch elements is increased due to generated frictional heat. In turn, non-uniform deformation is produced which influence the pressure distribution and thermal field. In other word, the contact pressure and high temperatures will be concentrated in small area of the contact zone that accelerates premature failure of the clutch system. Unfortunately, only few literature works explore through experiments the influence of temperature and other influent variables on the frictional behaviour of the clutch facing materials. In this study, the effect of sliding speed on temperature field and frictional behaviour of ceramic clutch pad was investigated to find out the safely working zone of dry friction clutch systems.

1. Introduction

During the early stage of friction clutch engagement, slipping occurs between the contacted surfaces and therefore, high power is dissipated. As a result, the frictional heat is generated at the sliding interface and produced high thermal field between the contacted surfaces of single-disc clutch elements (i.e. flywheel, pressure plate and clutch disc). The generated heat and forces would affect the temperature field and the pressure distribution due to producing non-uniform deformation. Consequently, high temperature and contact pressure will be concentrated in small area of the contact zone and may cause premature failure of the sliding system. The precautions that should be taken to



overcome this type of failure, safely working zone must be identified by deep investigation of thermal and frictional behaviours of the clutch system.

Abdullah wt. al. [1–15] studied the dissipated energy and thermal field of dry clutch considering uniform pressure and wear during the single and the multiple engagements. The effect of contact pressure between mating surface on the thermal field and internal energy is also investigated as function of time by using two methods: the ratio of heat partition method to determine the generated heat for each individual component while the second one takes the overall heat generation of the whole model by using contact model. Furthermore, they also investigated the influence of sliding speed, engagement time, thermal load, and disc on the thermal field of dry friction clutch during the first period of engagement.

Al-Shabibi and Barber [16] explored an alternative approach to find out the thermo elastic behavior with heat generation due to friction between contact parts. The sliding of two disks against each other was simulated by developing axisymmetric finite element model to investigate the pressure distribution and thermal field. Sliding speed was taken into consideration in this study with constant and variable level. The findings revealed that the crucial role is played by initial temperature because it stands for the particular solution and can has irregular pattern and this case is mainly correct when the sliding speed of contact parts are exceeded the critical level.

Lee et al. [17] investigated the behavior of pressure plate of clutch system when subjected to thermal loading, centrifugal force and contact pressure on the diaphragm spring. Both of thermal loading and contact pressure have shown significant effects that made the increasing of pressure plate thickness is necessary issue to improve the heat capacity and reduce thermal stresses.

Gao and Barber [18] adopted the Berger's model and equations of torque to simulate the wet clutches at the engagement stage. They selected six parameters to investigate their effects on the engagement time and torque of the wet clutch system. The results showed that the viscosity and friction affected both of engagement time and output torque. Furthermore, the engagement time is highly influenced by moment of inertia compared with torque response. Finally, the torque is less affected by Young's modulus, permeability, and groove area.

Zagrodzki [19] investigated the frictional heating and stability of sliding system when sliding speed is exceeded the magnitude of critical speed. The developed FE model was utilized to study transient thermoelastic problem, and both of spatial discretization and modal superposition is proposed. The solution was consisted of homogenous (initial condition) and nonhomogeneous parts (background process). The simulation results revealed that the significant variable that impact the back-ground process are distribution of uniform pressure in isothermal situation and pressure varieties that may cause either by the geometric imperfection or by design attributes.

Shahzamanian et al. [20] examined the contact and transient analysis of brake disk made of functionally graded material (FGM) brake disk. The analysis takes into consideration the coulomb contact friction between the friction pad and brake disk. It was pointed out that the contact pressure and total stress is positively related with contact stiffness factor.

Gao and Lin [21] analyzed the thermal field for solid rotor of brake system by developing the transient FE model and applying the suitable boundary conditions. They considered the variation of moving heat source represented by the pad relative to the sliding speed. The analysis of results showed the potential effects of brake operating features on the distribution of surface temperatures.

The heat generation and wear rate is significantly affected by the sliding speed due to friction between contact parts. Also the sliding speed and contact pressure impact the distribution of surface temperatures of the clutch system. As a result, the surface softening and decreasing of friction would happen with increasing of sliding speed. This relationship plays a crucial role in computing the possibility of shudder for any sliding clutch system [22, 23]. Senator et al. [24] studied the effect of sliding speed on the coefficient of friction of brake and clutch facing specimen during the transient operation. The experimental results have been simulation using the artificial neural network to obtain a comprehensive view of the impact of sliding conditions.

Pisaturo M. and Senatore A. [25] developed a thermal model to estimate disk and cushion spring temperatures of automated dry clutch. The proposed model has been validated by using non-linear least square approach to compare simulations with FE results. Then, they proposed control strategy

according to the predictive thermal model in order to perform simulation of lurch maneuvers of the vehicle with high temperatures in flat and uphill conditions. In order to prove the reliability of the presented control method, it has been compared with PI classical control strategy. et al [26] which proposed a new approach to identify and estimate directly the parameters of clutch torque based on measured signal of engine speed and torque through multiple predictive control model. The effectiveness of the proposed methodology has been tested on turbocharger 1.3 L diesel engine with six speeds automated manual transmission system.

This research paper provides a detailed experimental study of the interactive effect of sliding velocity and contact pressure on frictional characteristics (coefficient of friction) and the generated surface temperatures that approach between the two contact surfaces. It was selected a rang of the velocities (0.5-3 m/s) and contact pressure (80-120 kPa). It was selected the ceramic material as clutch pad to conducting the experimental tests. The main objective of this research paper is to determine the safely working zone of the sliding system to avoid as much as possible the premature failure.

2. Experimental Work

This section describes the experimental setup and the instrumentations that have been used. The pad-on-disc tribometer (Wazau TRM 100 model) was selected to conduct the frictional behavior experiments of facing material at laboratory scale. The calibration was performed for the test rig. Its maximum normal load and measurable frictional torque are 100 N and 2 N.m respectively. The tribometer, data acquisition device (DAQ NI-9171USB/NI-9211 model) and type K thermocouple are shown in Figure 1. The set-up was based on a pad-on-disc frictional conjunction. The configuration of the facing materials is rectangular pad that was extracted from clutch facing annular disc and glued on steel pin that is fixed on stationary holder. It is asbestos-free material, not reinforced, and does not involve any metal. This frictional material is useful for clutch facings for passenger cars and trucks, outside shoe brakes and disk brakes in construction and engineering. It has density of $2.05 \text{ [g/cm}^3\text{]}$ at $20 \text{ }^\circ\text{C}$ exhibiting good resistance against ATF-oil. The disk external radius is 40 mm and the contact area becomes $5 \times 10^{-4} \text{ m}^2$. The tribometer disc was made from X155CrVMo12 steel with 60 HRC hardness and surface feature similar to mid-worn pressure plate of real cultch system. The thermocouples joints were inserted in the pad to capture thermal level at both ends of sliding path. The fixing was made through the support base that fixed under the graduated crossbars. The experimental set up is shown in Figure 2.

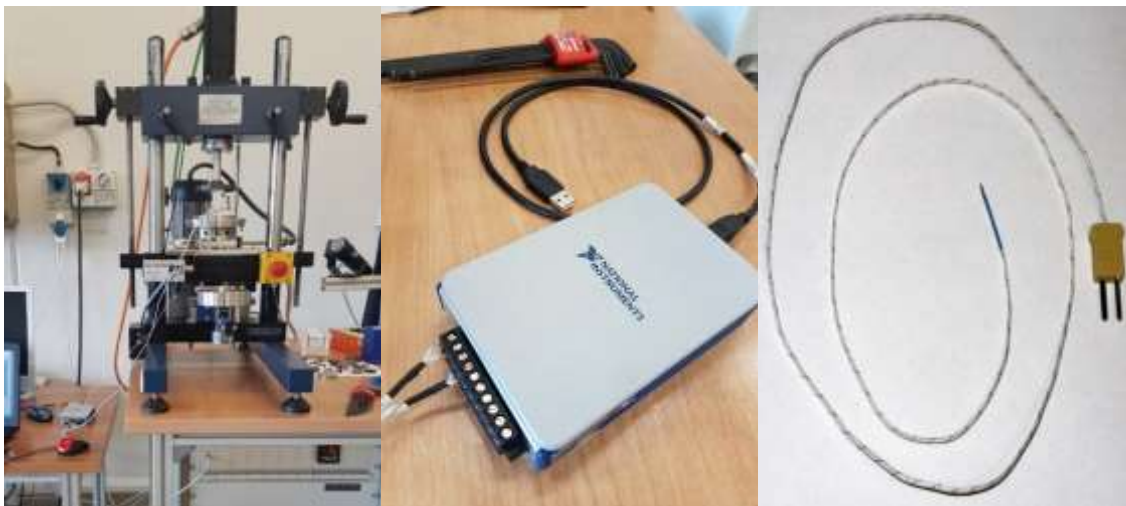


Figure 1. Tribometer Wazau TRM 100, b. Devices for acquisition: DAQ NI-9171USB/NI-9211, c. type K thermocouple

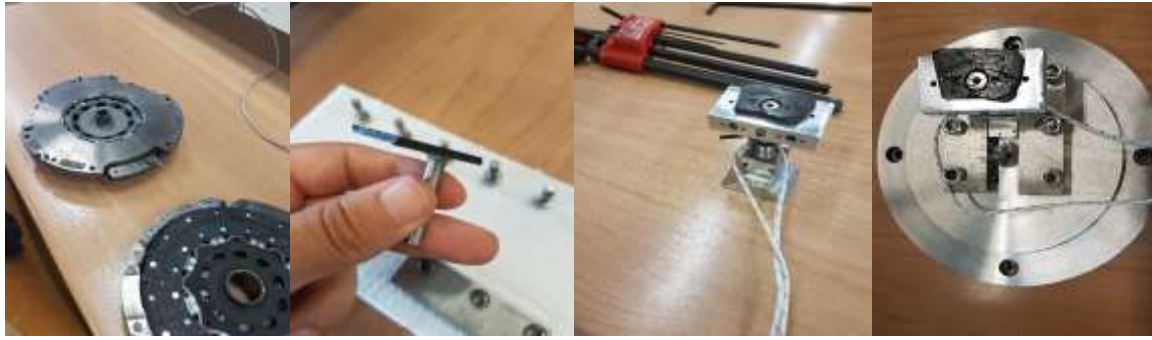


Figure 2. Experimental set up

Table 1 lists the operating parameters of the pin-on-disk sliding system. It is obvious that each of average contact pressure and clamping load have three levels, while seven levels of sliding speeds were selected. By setting the input parameters, i.e. sliding speed, clamping load, average contact pressure, and radius r_m . The value of the friction coefficient μ and temperature are obtained, in real-time mode. The applied (normal) load was directly measured by way of a load cell.

Table 1. Formatting sections, subsections and subsubsections.

No.	Parameters	Units	Levels
1	Sliding speed	(m/s)	0.5, 1, 1.5, 2, 2.5, 3.
2	Rotational Speed	rpm	120, 240, 350, 480, 600, 720
3	Average contact pressure	kPa	80, 100, 120
4	Clamping load	N	40, 50, 60

3. Results and Discussions

In this section, the achieved results from the conducted experimental part of the preceding section will be tabulated, figured, and discussed. Where, two preliminary tests were performed. The first preliminary test was carried out to analyze the eventual unfavourable effect due to additional frictional reaction due to rubbing thermocouple junction against disk. Figure 3 shows the relationship between coefficient of friction and time in second. It reveals four zones namely: transitional phase, value of μ in steady state, temporary alteration for thermocouple removal, and recovery of the previous μ value. In general, the result showed no alteration of frictional torque measured by the instrument when the rubbing thermocouple has been included in the setup.

From the other hand, preliminary test 2 was executed to analyze the local heat generation in the small volume around thermocouple junction as shown in Figure 4. When the disk rotation is suddenly stopped. The measured temperature is still the same: thus, no false detection is generated as result of local frictional heating of thermocouple tip.

The friction pad has been tested after adequate running-in of 3600 m as sliding distance. Table 2 shows the measured temperatures and coefficients of friction for various settings of sliding velocity, rotational speed, and average contact pressures. The minimum and maximum values were also recorded. For more clarification, the collected results shown in Table 2 would be visualized in contour plots to identify significant zones. Figures 5 and 6 illustrate the contour plots of the variation of coefficient of friction and surface temperature with sliding velocity and average contact pressures, respectively.

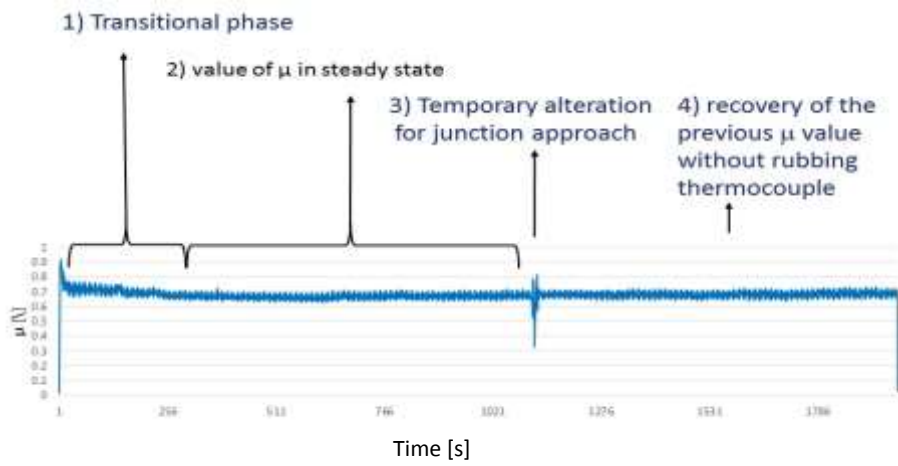


Figure 3. Preliminary test 1

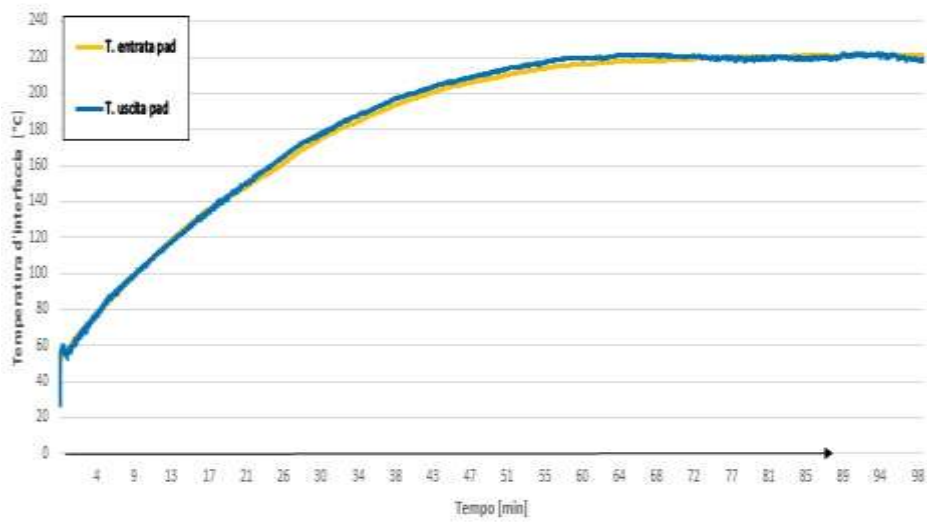


Figure 4. Preliminary test 2

Table 2. Experimental results

No.	Contact Pressure 80 kPa			Contact Pressure: 100 kPa			Contact Pressure 120 kPa		
	sliding velocity (m/s)	Temperature (°C)	Coefficient of friction (μ)	sliding velocity (m/s)	Temperature (°C)	Coefficient of friction (μ)	sliding velocity (m/s)	Temperature (°C)	Coefficient of friction (μ)
1	0.5	83	0.75	0.5	86	0.70	0.5	98	0.73
2	1.0	99	0.77	1.0	115	0.72	1.0	129	0.72
3	1.5	113.5	0.77	1.5	131	0.70	1.5	148.5	0.71
4	2.0	143.5	0.71	2.0	159	0.68	2.0	169.5	0.68
5	2.5	153.5	0.65	2.5	160	0.63	2.5	219.5	0.67
6	3.0	179.5	0.65	3.0	195	0.62	3.0	227	0.55
max		179.5	0.77		195	0.72		227	0.73
min		83	0.65		86	0.62		98	0.55
mean		128.6667	0.717		141	0.675		165.25	0.677
STD		36.37673	0.0561		38.476	0.041		50.777	0.066

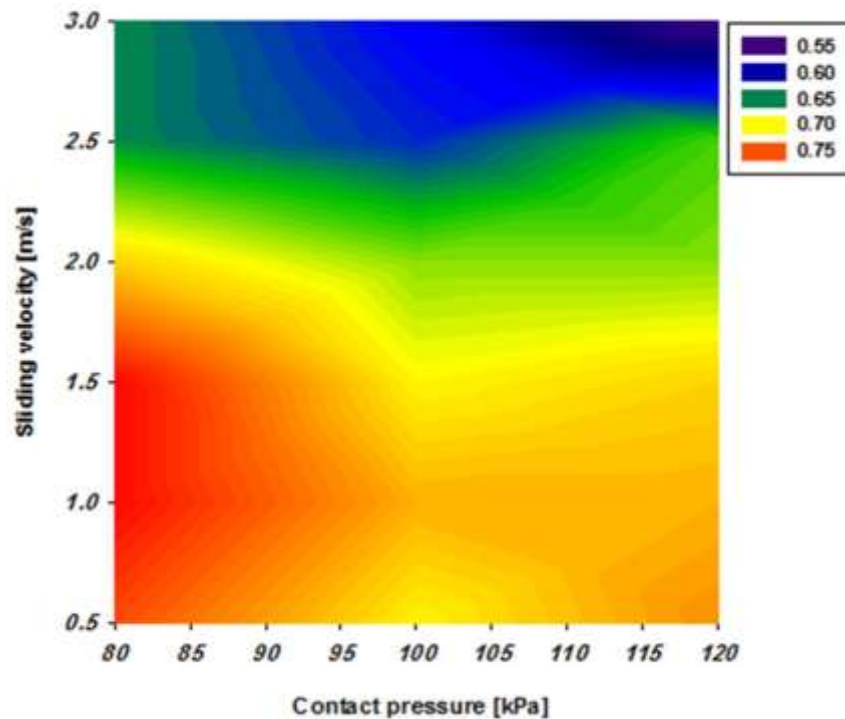


Figure 5. Contour plot of sliding velocity against contact pressure for coefficient of friction response.

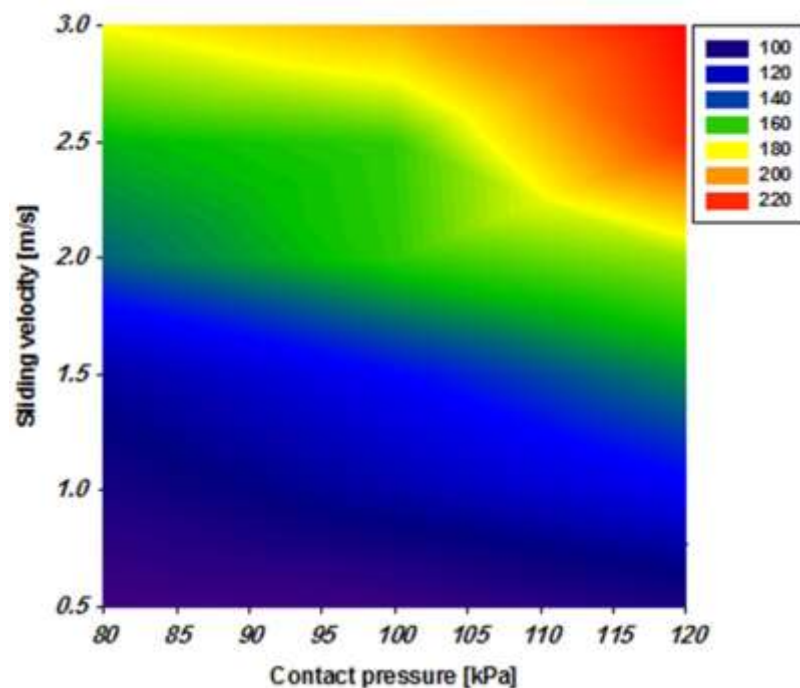


Figure 6. Contour plot of sliding velocity against average contact pressure for temperature response.

It can be observed from Figures 5 and 6 that, at early stage, the coefficient of friction is relatively constant with increasing of sliding speed at low contact pressure level. The increasing of sliding speed reduces the coefficient of friction especially at the last two speeds (i.e. 2.5 and 3 m/s). At the beginning, the frictional heat is not so high due to low contact pressure and sliding speed. Thus, the evolved temperature will not be high enough to soften the frictional material under investigation. In

other word, the reduction in the coefficient of friction for this setting is generally low. Even with increasing the average contact pressure, there is no noticeable reduction in coefficient of friction when the sliding speed is below (2 m/sec). The increasing of contact pressure at the X-axes while keeping low sliding speed would not reduce coefficient of friction significantly. From the other hand, high level of sliding speed with low contact pressure produces significant reduction in friction coefficient compared with previous parameters. The dark orange refers to the maximum coefficient of friction zone while minimum coefficient area is characterized by purple color.

Figure 6 exhibits the contour plot of sliding speed against average contact pressure for temperature response. More increasing of sliding speed causes drop in the coefficient of friction and rise in the temperatures. Comparing the coefficients of friction and temperatures values in Table 2 at 80 and 100 Kpa reveals that the average contact pressure combined with sliding speed generate additional frictional heat which rise up the corresponding temperatures. In general, the friction coefficients for both pressures are relatively comparable that reflects the thermal stability of utilized frictional material when subjected to more pressure. Dark blue and green zones locate the maximum and minimum temperature areas, respectively.

The significance impact of sliding speed starts to reveal when accompany with high levels of average contact pressure and rotational speed. In other word, by increasing the average contact pressure and rotational speed to 120 kPa and 3.0 m/s, causes more and additional frictional heat as indicated in the last two measurements of coefficients of friction and temperatures. The remarkable impact of average contact pressure on both responses starts to appear at high level interactively with high sliding speed. Comparatively, the high sliding speed maintains low coefficient of friction and high temperature even at low to medium contact pressure. This could be explained that high normal contact pressure enlarges the contact surface area that subjects asperities to more plastic deformation, which led to energy dissipation especially when combined with high sliding speeds [27]. Hence, more frictional heat is generated at sliding velocities of 2.5 and 3 m/s that cause significant reduction in the coefficient of friction and noticeable increment in the level of temperature. The raising of temperature due to sliding speed and contact pressure results in reduction of the adhesion between the frictional surfaces and steel pin [28]. This trend can be rationalized within adhesive theory frame of friction to produce good self-lubrication and surfaces protection to [29, 30].

From statistical point of view, the maximum standard deviation was recorded for third set of experiments due to high contact pressure and sliding speed. These conditions ensure high fluctuations of coefficient of friction and temperature values around the mean. In other word, these conditions guarantee maintain high frictional heat that reflected on the friction coefficient and temperature response. Therefore, the safe working zone could be achieved, and premature failure may be avoided if high contact pressure and sliding speed is not chosen.

4. Conclusions

A series of experimental tests were achieved to study the interaction influence of the sliding velocity and contact pressure on the coefficient of friction and surface temperature. The experiments performed on clutch materials with results and discussions of previous sections allow to list the following items:

1. The free asbestos friction materials achieved good tribological performance and thermal stability.
2. Sliding velocity showed significant impact on both coefficient of friction and temperature.
3. If safe working zone has to be achieved to prevent premature failure, long phases with high sliding speed and average contact pressure should be avoided.

The influence of temperature on friction coefficient has been confirmed also for selected material, and such a sensitivity needs a careful compensation strategy in automated clutch system for proper control of engagement behaviour.

References

- [1] Abdullah O, Schlattmann J, Majeed M and Sabri L 2019 *International Journal on Interactive Design and Manufacturing (IJIDeM)* **13** 487.
- [2] Abdullah O, Schlattmann J, Majeed M and Sabri L 2018 *Case studies in thermal engineering* **11** 43.
- [3] Abdullah O, Schlattmann J, Senatore A, and Al-Shabibi A 2018 *Heat and Mass Transfer* **54** 3461.
- [4] Sherza J, Hussain I Y, and Abdullah O In 2018 *International Conference on Advanced Science and Engineering (ICOASE)* 474 Duhok-Iraq.
- [5] Abdullah O, Majeed M, and Hussain I Y 2018 *Materials Science and Engineering* **433** 012044.
- [6] Abdullah O, Schlattmann J, Jobair H, Beliardouh N, and Kaleli H 2018 *Industrial Lubrication and Tribology* **72** 1.
- [7] Abdullah O, Rasham A, and Jobair H 2018 *FME transactions* **46** 33.
- [8] Stojanović N, Glisovic J, Abdullah O, Grujić I, and Vasiljević S 2019 *Thermal Science* **24** 203.
- [9] Abdullah O, and Schlattmann J 2017 *Tribology Transactions* **60** 1011.
- [10] Abdullah O, and Schlattmann J 2016 *Friction* **4** 228.
- [11] Abdullah O, and Schlattmann J 201 *Friction* **4** 135.
- [12] Abdullah O, Akhtar M, and Schlattmann J 2015 *Journal of Tribology* **137** 11703 .
- [13] Sherza J, Hussain I Y, and Abdullah O 2019 *Journal of Mechanics of Continua and Mathematical Sciences* **14** 41.
- [14] Abdullah O, Schlattmann J, Hussain I, Abd Al-Sahb W 2019 *Jurnal Tribologi* **20** 114.
- [15] Abdullah O, Sabri L, and Abd Al-Sahb W 2016 *Tribologia* **2016** 9.
- [16] Al-Shabibi A M, Barber J R 2009 *J Therm Stresses* **32** 226.
- [17] Lee C Y, Sup C I, Chai Y S 2007 *J Key Eng Mater* **353–358** 2707.
- [18] Gao H, Barber G C 2002 *Tribol Trans* **45** 464.
- [19] Zagrodzki P 2009 *Int J Solids Struct* **46** 2463.
- [20] Shahzamanian M M, Sahari B B, Bayat M, Ismarrubie Z N, Mustapha F 2010 *J Mater Design* **31** 4655.
- [21] Gao C H, Lin X Z 2002 *J Mater Process Tech* **129** 513.
- [22] AL-Alawi A, Yousif A, Jassim M 2007 *Al-Khwarizmi Eng. J.* **3** 49.
- [23] Al-Shabibi A M 2014 *Tribol Trans* **57** 1164.
- [24] Senatore A, D'Agostino V, Di Giuda R, Petrone V 2011 *Tribology International* **44** 1199.
- [25] Pisaturo M, Senatore A 2019 *International Journal of Automotive Technology* **20** 1089.
- [26] Sharifzadeh M, Pisaturo M, Senatore A 2020 *Proc IMechE Part D: J Automobile Engineering* **234** 586.
- [27] Mahmud D N F, Abdollah M F B, Masripan N A B, Tamaldin N, Amiruddin H 2017 *Industrial Lubrication and Tribology* **69** 945.
- [28] Hatipoglu G, Kartal M, Uysal M, Cetinkaya T, Akbulut H 2016 *Tribology International* **98** 59.
- [29] Straffelini G, Pellizzari M, Maines L 2011 *Wear* **270** 714–719.
- [30] Luo Q 2013 *Encyclopedia of Tribology* 3760.