Comparative Thermal Stability and Heat Transfer Capability for Various Materials for Belt Conveyor Disc Brake

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Abstract

The obligatory demands on the belt conveyor braking system under a wide variety of operating conditions are high and diverse. Improvements in the operating conditions of conveyor belt systems are made more difficult because braking is deterministic by nature. The performance of the belt conveyor brake mainly affected the role of the braking system because its performance was due to complex inter-related phenomena in contacts of different friction pairs. The main purpose of this study is an investigation with ANSYS software code to test the behavior of a disk under the same static and geometry profile for a solid conveyor disc brake during continuous braking. This paper examines the behavior of disk material braking efficiency under thermal and imposed heat condition. Finite element method (FEM) were used to perform the analysis on four materials of brake disc. The study will focus on different performances on heat flow, the distribution of temperature and disk damage via deformation. Comparison of the results achieved with those of the technical literature and simulation, have been found satisfactory.

Keywords
Disc Brake, Heat Flux, Heat Dissipation, Finite Element Analysis

1. Introduction
In view of our scientific and technological advancements and the rise in coal seam production, coal mines need longer and longer, high-capacity, large drop angle declined conveyor belts (Fangwei *et al*, 2011). It was also shown that belt conveyors are one of the most efficient means to transport bulk solid materials (Lodewijks, *et al*., 2016). Because of their inherent advantages like high capacity and reduced labor demands, belt conveyors play an important role in bulk solid handling and transportation, particularly in areas with limited or non-existent transport infrastructures(He *et al.*, 2018).

The safety of the downstream conveyor frequency brake systems is a key requirement. Today, overland downstream conveyors usually use large disk brakes at the end of the conveyor system (Fangwei *et al*, 2011). The temperature gradient on the brake disks results in high thermal stress and fatigue failures, thus decreasing braking power and reducing braking protection. Profound work is therefore required on the distribution of friction pair temperature fields (Daoming *et al*, 2011). The fact that the braking mechanism has stochastic characteristics affected by the changes of the real contact area scale, transfer layer existence between friction pair, increasing strain, temperature, speed, deformation and wear complicates the improvement of the conveyor brake efficiency under different operating conditions (Aleksendric *et al*, 2008) In addition, due to heat generation at the interface of the disks and pads, global deformation such as coning and buckling occurs in the disks and pads resulting in disc cracks (Jaiswal *et al.*, 2016). The effect of radiation heat transfer on the total amount of dissipated energy to the surrounding area during normal braking is negligible and heat transfer modes of conduction and convection play a crucial role in the heat exchange

contribution of the brake system (Ghadimi *et al*, 2013). Thermal analyzes are conducted in this paper for the finite element (FE) model of a disk brake assembly development, using the ANSYS 19.2 FE program, to obtain heat transfer distribution on brake disk. A nonlinear finite element approach will be used to simulate the temperature field and transient-thermal performances on four different steel material with conclusion of which material give better results under dynamic braking toque and similar disc external geometry.

2. Literature Review
2.1 Material properties used for the disk brake
One dynamic and persistent goal in engineering is to develop performance relationships between all the variables and parameter in a system, in mathematical form (Meng *et al*., 1994). The wider friction signature of the brake system is regulated in the tribological interface by a metaphysical dynamic. Partially the particle adheres to the disc surface, coming into the contact zone again in the next revolution (Hamid *et al*, 2011). It is expected that for good performance the disks used are thermally stable, wear resistive and thermal fatigue resistant. Thermal fatigue is due to the internal stress generated during braking when the surface matter is expanded and compressed relative to the surface of the material (Juvinall *et al*, 2012).

The brakes transmit mechanical strength during braking and dissipate the generated heat during operation, which contributes to disc exposure to thermo-mechanical fatigue load conditions differ from the ambient temperature to as much as $800°$ C, depending upon their intensity and number of braking (Maluf, *et al*., 2004). If heat is generated faster that it can be dissipated, the results may lead to disc failure of sort. Disc brake heat dissipation capability must be designed to prevent temperatures that are harmful to components of the brake system (Budynas, *et al*, 2011). Gray cast iron with mainly pearl-like material is the common material for brake discs. The advantages of using cast iron as a disk are high wear-ability and simplified manufacturing process. High thermal conductivity and heat capacity, resistance to brake fade and lowers cost (Rashid *et al*, 2014). For this study the following material will be investigated: Cast Iron; Aluminium; Stainless Steel and Mild Steel. The material properties are given in Table 1.

Table 1 Brake disc material properties

Properties	Aluminium	Mild-Steel	Grey Cast Iron	Stainless steel
Density (Kg/m³)	2770	8200	7200	7750
Coefficient of Thermal Expansion (1/C)	0.000023	0.000012	0.000012	0.0000175
Thermal Conductivity (w/m. K)	23	38	52	15
Young's Modulus (MPa)	69000	210000	125000	193000
Shear Modulus (MPa)	26669.2	81000	120000	74000
Specific Heat (J/Kg/C)	875	470	586	420
Compression Yield Strength (MPa)	280	250	350	280
Mass of disk (Kg)	96.1883	308.453	250.02	269.118
Poisson's Ration	0.33	0.30	0.280	0.31
Specific Heat (J/Kg/C)	875	470	586	420
Disk Heat Generated (KJ)	5937,720	3189,404	3223,257	2486,668
Brake surface area (m²)	0.300415	0.300415	0.300415	0.300415
Duration of braking (sec)	30	30	30	30
Disk Heat Flux (W/m²)	658.8353	353.888	357.645	275.915

2.2 Brake disc thermal analysis
The downward belt conveyor brake system is a method of energy conversion in which power is mainly absorbed by the disk frequency by the kinetic energy transferred from the conveyor and product (Youfu *et al*, 2011). The main problem with the operation and performance of disk brakes is the consequence of the temperature produced by braking on the friction of operating elements and the stability of its performance (Osenin *et al*, 2017). Due to thermal expansion, non-uniformity of the time-spatial temperature field creates thermal stress. This thermal pressure will in turn cause expansion and micro-cracks on the disk's friction surfaces, their development and disabling the correct and healthy use of a disk brake system (Adamowicz *et al*, 2016). Heat dissipation, known as friction heating, is responsible for temperature increases in sliding bodies within the contact area and affects the tribological activity and failure of sliding components, deterioration of the surface, melting of the contact solids and fading of the brake disks (Kennedy *et al*, 2000).

It should be remembered that thermoelastic instability results from a system stress disruption, causing the accumulation of more energy at one point in the disk. This location gets warmer than the neighboring material suggesting the presence of these stress disturbances (Islahi *et al*, 2017). The heat of the disc undeniably evokes uniform temperature distributions in the disk's domain, whereas during mutual sliding the friction pad element is constantly heated (Goo *et al*, 2010). The break disk should be configured to provide adequate thermal storage space for thermal distorting or cracking until the heat is reasonably discharged (Maleque *et al*, 2010). The uneven temperature distribution on the disc lead to heat distortion, known as the coning, that is responsible for the effect on the disc in the long run (Jaiswal *et al*, 2016).

2.3 Heat flux entering the brake disc

The heat exchange conditions during the braking process are highly dependent on the changes in the temperature field. The input heat stream depends largely on the friction coefficient and the angular velocity of the disk, while the friction pair material and external environmental factors are the subject of the exchange of heat (Cho *et al*, 2014). During braking, kinetic energy is converted to thermal energy due to the first law of Thermodynamics. The power conversion takes place due to friction between the main components of the disk brake (Nouby *et al*, 2013). To achieve heat flow on two component surfaces of a brake system, we break the amount of thermal energy into each component's surface contact area (Talati *et al*, 2009). The thermal conveyance of the material of the brake pads is usually less than on the disk ($K_{pad} < KW_{disc}$) because the amount of heat generated can be absorbed completely by the disk. The thermal flow from this surface is the same as the friction force (Belhocine *et al*, 2012). The initial flux of energy hitting the disk is determined by Equation 1, as below:

$$q_0 = \frac{(1-\emptyset)}{2} \frac{mgvz}{2A_d\varepsilon_p},$$

Eq (1)

where q_0 heat flux entering the disc, z = a/g is the braking effectiveness, Ø is the rate distribution of the braking forces, A_d disc surface swept by a brake pad, v is the speed of the conveyor, ε_p is the factor load distribution on the disc surface, m is the mass of moving material and g is the acceleration of gravity. The heat flux can be simplified as the heat generated per second per squire area of disk and pad contact area (Deekshith *et al*, 2017). Heat flux generated in the disk blade in simplification be calculated as per Equation 2:

Heat generated   Q = m.Cp.ΔT

Eq (2)

where m is the mass of material, Cp is the specific heat and ΔT is the temperature rise
Heat Flux   q = Heat Generated /Second /area

The brake disc is sized to permit the accumulated heat to be absorbed and dissipated to prevent disc premature failure. Thermal analysis of the brake system will be carried as formulated below in Equations (3-5) to determine whether additional cooling is required (Golka, *et al.*, 2007).

$$W_b = \frac{1}{2}M_{br}\omega t_b \quad \text{Friction energy}$$

Eq (3)

$$\triangle T = \frac{W_b}{C_{sh}*m_d} \quad \text{Heating up during braking process}$$

Eq (4)

$$\triangle T_{max} = \frac{2R_e}{E\alpha_{th}} \quad \text{The temperature shall not exceed}$$

Eq (5)

Where, M_{br} is the applied braking torque, t_b is braking or stopping time, ω is the disc rotational speed, C_{sh} is specific heat, m_d is the disc mass, R_e is the yield strength, E is the modulus of elasticity and α_{th} is coefficient of thermal expansion. The conversion of heat loss of the brake element creates a decrease in internal energy of the element. The temperature response of the brake can be calculated as per Equation 6 below (Islahi *et al*, 2017).

$$T = (T_{max} - T_a)e^{-t.\pi} + T_a$$

Eq (6)

When the surface temperature first rose and then falls, the maximum temperature transpired before the point of disturbance, not at the end of the period, this is a dynamic process through the entire breaking time (Youfu *et al*, 2011).

3. Case Study and Formulation of the Problems

Sidewinder Engineering software has been used as a design tool for a 2.1637Kilometer overland conveyor with the results as indicated in Table2 below. The designed disk brakes have a diameter of 135mm and 465mm bore with a thickness of 30mm as shown by Figure 1. The braking time suitable to stop the conveyor will be 30sec under normal operation. Normal operating conditions are steady state running, loading and unloading; which conveyor experience at various frequencies. The Conveyor Profile of a fully loaded with material Lift -11.7 m is shown in Figure 2.
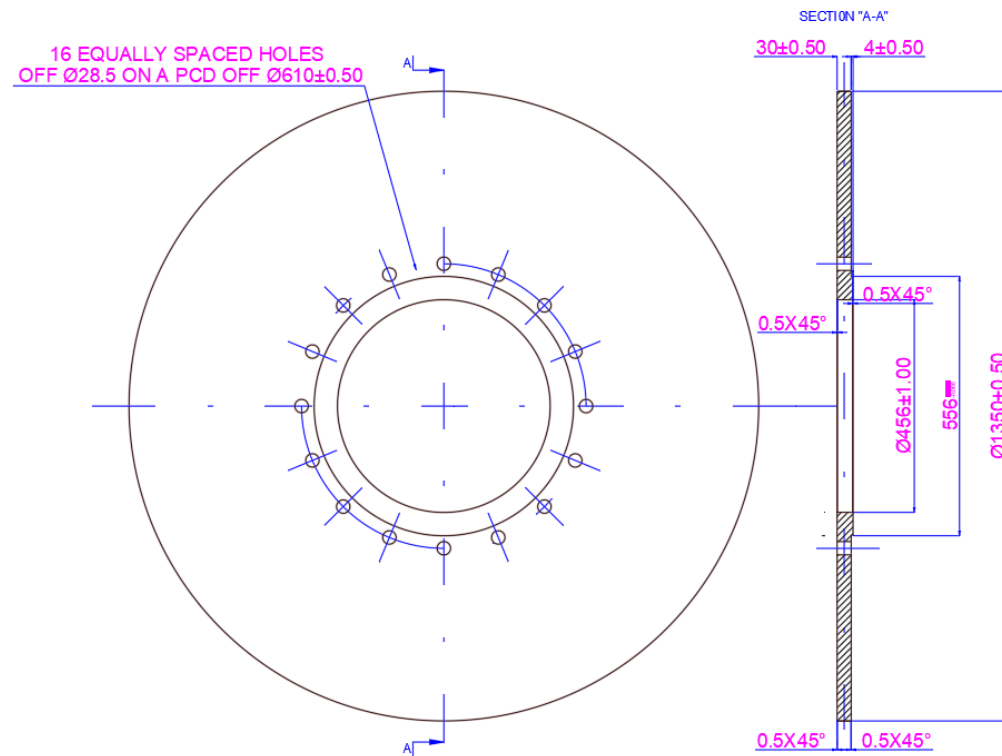
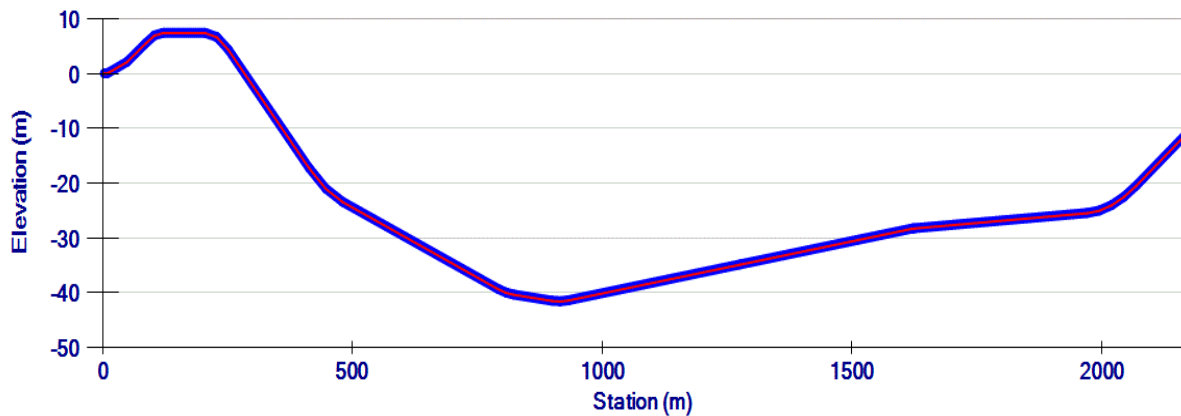

Figure 1. Brake disc assembly drawing

Figure 2. Overland conveyor profile

Table 2. Conveyor design calculation input data

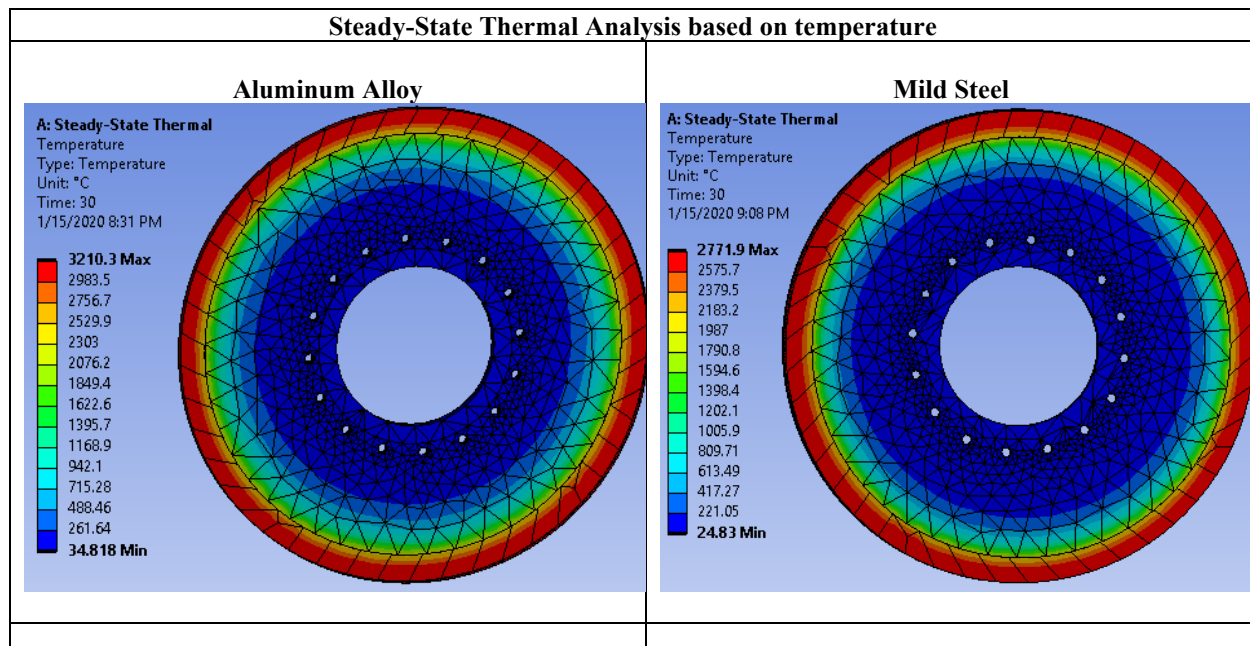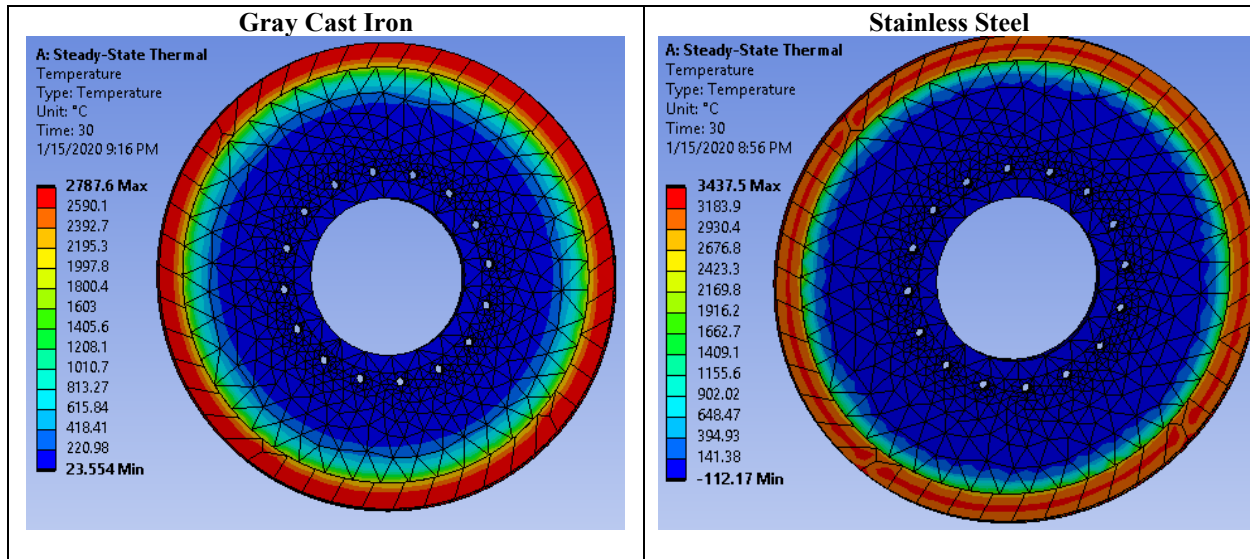| Properties Description	Value	Properties Description	Value
Power Breakdown		**Belt Output Data**	
Total installed power (kW)	**1200**	Speed (m/s)	4.4
Max demand power (kW)	**1243**	Width (mm)	1800
Conveyor Profile Summary		**Brake Torque Design Range**	
Length (m)	2163.7	Brake location	Tail Pulley
Height (m)	-11.7	Quantities of brakes	1
Minimum Elevation (m)	-42.4	Brake Torque (N.m)	145,000
Maximum Elevation (m)	7.4	Pulley Diameter (mm)	1000
Material Properties		Brake Disk diameter (mm)	1350
Type	COAL	Disk thickness (mm)	30
Through-put Tonnage (t/h)	4800	Force Applied to Disk (N.m)	320,000
Density (kg/m³)	1050	Disk rotational speed (RPM)	86
Coal Lump size (mm)	300	Frequency (Hz)	60

4. Results and Discussion

In the multi-physical module ANSYS Workbench, the boundary conditions are added, the first simulation mode is chosen (permanent or interim) and the physical properties of the materials are described. Once these parameters have been fixed, a boundary condition associated with each surface is introduced (Belhocine *et al*, 2014):

4.1 Steady-State Thermal Analysis based on Temperature Simulation Results

Repeated cycles may consist of frictional heat generation in brakes. Characteristic of this cycle is that, after short periods of heat dissipation, the brake does not cool to the starting point; thus, the contacting elements bulk temperature is increased (Gezes et al, 2019). The investigation of steady state thermal analysis is based on temperature retainment as shown in Table 3 where the maximum temperature is retained in the area were the brake disc interfaces with the brake pad and low temperatures are observed on the coupling of the brake disc on the inner radius of the disc. Mild steel and grey cast iron scored similar pattern of temperature absorption of 2771.9° and 2782.7° respectively on the outer circumference of the disc. Under the same set of domain condition, aluminum attracted a lot more temperature to a maximum of 3210,3° and this demonstrates that material properties for aluminium has capability of attracting more temperature quickly.

Table 3 Brake disc steady state thermal analysis (temperature based)

Gray Cast Iron	Stainless Steel
A: Steady-State Thermal Temperature Type: Temperature Unit: °C Time: 30 1/15/2020 9:16 PM **2787.6 Max** 2590.1 2392.7 2195.3 1997.8 1800.4 1603 1405.6 1208.1 1010.7 813.27 615.84 418.41 220.98 **23.554 Min**	**A: Steady-State Thermal** Temperature Type: Temperature Unit: °C Time: 30 1/15/2020 8:56 PM **3437.5 Max** 3183.9 2930.4 2676.8 2423.3 2169.8 1916.2 1662.7 1409.1 1155.6 902.02 648.47 394.93 141.38 **-112.17 Min**

Stainless steel simulation results illustrate temperature difference between the outer and inner radius ranging from minus 112.17 ° to as high as 3437.5° on the disc outer diameter. The results for stainless steel which includes a negative value on the inner disc bore, may answer future question such as variance in temperature which may lead to brake disc wrapping, cracking or failure of some sort. Cooling on the disc's outer radius and warming up on the inner radius is unusual.

The rate at which the energy is carried out as heat between the two bodies depends on the temperature differential between the two surfaces and the properties of the conductive interface by which the heat is transferred. Heated material with strong thermal expansion results in an rise in volume size and thus a significant change in temperature relative to low thermal expansion material (Yakout et al, 2018). The graphic difference in performance for different disc material in terms of temperature rise is illustrated in Table 4 below. From the results it is observed that aluminium and stainless steel recorded high temperature rise as a consequence of the high coefficient of thermal expansion and lower thermal conductivity for each material property. Aluminium has the highest coefficient of thermal expansion of $17.5x10^6 \ (l/c)$ followed by stainless steel which is recoded to be $23x10^6 (l/c)$ as indicated in Table 5 below.

Table 4 Steady state brake disc temperature rise comparative results

Steady-State Thermal Analysis Based on Temperature				
Time (Sec)	**Alluminum**	**Mild Steel**	**Gray Cast Iron**	**Stainless Steel**
3	34.818	24.83	23.554	-112.17
5	261.64	221.05	220.98	141.38
7	488.46	417.27	418.41	394.93
9	715.28	613.49	615.84	648.47
11	942.1	809.71	813.27	902.02
13	1168.9	1005.9	1010.7	1155.6
15	1395.7	1202.1	1208.1	1409.1
17	1622.6	1398.4	1405.6	1662.7
19	1849.4	1594.6	1603	1916.2
21	2076.2	1790.8	1800.4	2169.8
23	2303	1987	1997.8	2423.3
25	2529.9	2183.2	2195.3	2676.8
27	2756.7	2379.5	2392.7	2930.4
29	2983.5	2575.7	2590.1	3183
30	3210.3	2771.9	2787.6	3437.5

4.2 Steady-State Thermal Analysis based on Total Heat Flux

The amount of heat transferred by area per unit to or from the surface is the heat-flow or thermal flux strength. It is both directional and magnitudinal and therefore a vector quantity. The amount of heat transmission per unit time and the area from which the heat transmission takes place (Dhakar *et al*, 2016). Thermal heat-flux analysis conducted on the four prescribed material are shown in Tables 5 and 6, and comparison of results are given in Table 7. Heat flux for aluminum rises higher than all the other material with a maximum value of $7377 \times 10^3 (W/m^2)$ and stainless steel has the lowest rise in heat flux with highest value at $1779 \times 10^3 (W/m^2)$, however the results shows low heat transfer on the inner radius for this material.

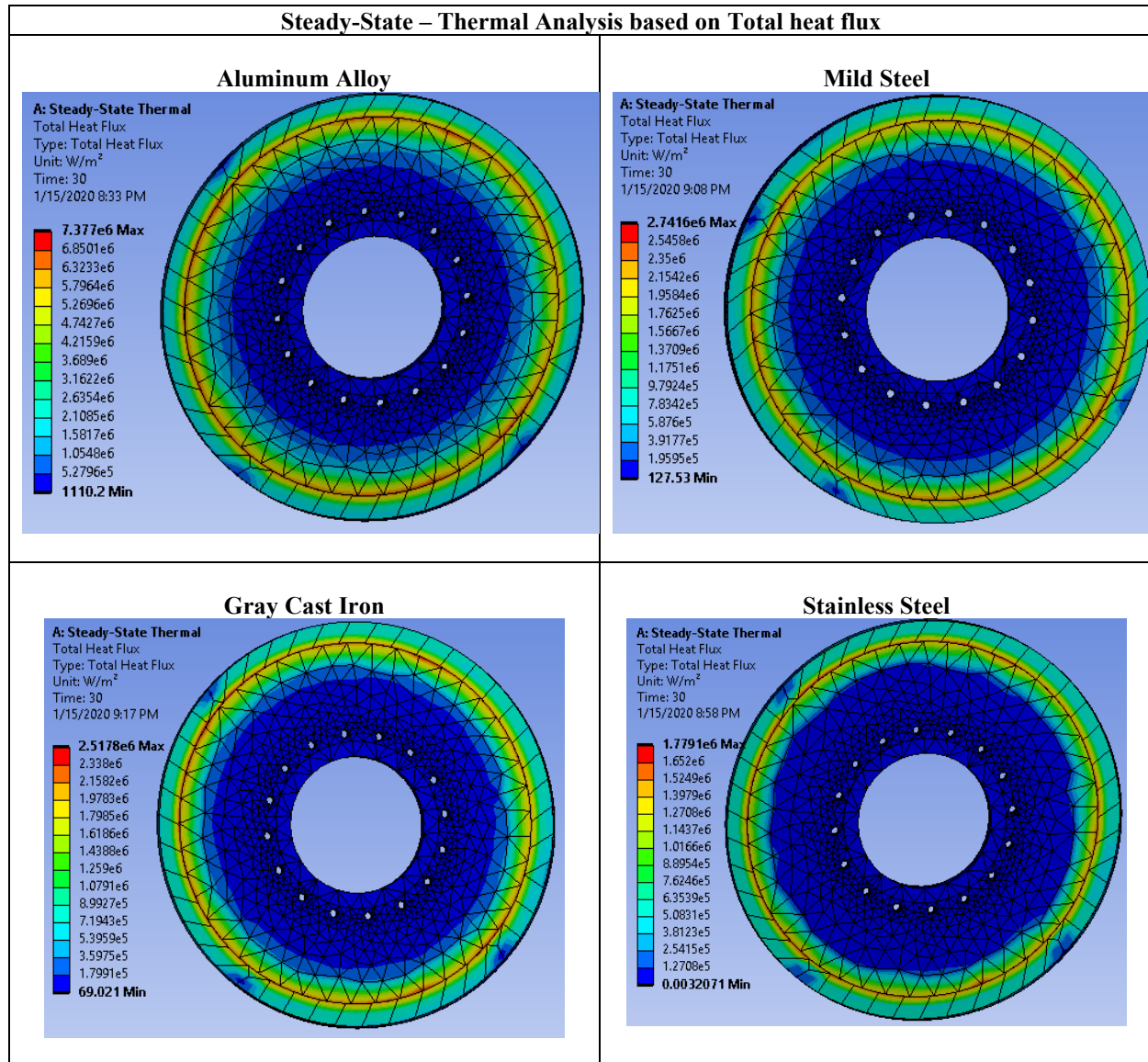Table 5 Brake disc steady state thermal analysis (total heat-flux based)

Table 6 Brake disc heat-flux range

Heat Flux results	Aluminum	Mild-Steel	Grey Cast Iron	Stainless steel
Min – Heat-flux (W/m²)	1110.2	127.53	69.021	0.0032071
Max - Heat-flux(W/m²)	7377×10^3	2741.6×10^3	2517.8×10^3	$1779,1 \times 10^3$

Table 7 Steady state brake disc heat flux comparative results

Thermal Analysis based on Total Heat Flux			
Time (Sec)	Alluminum	Mild Steel	Gray Cast Iron	Stainless Steel
3	1.1102	0.12753	69.021	0.00327
5	52.796	195.95	179.91	127.08
7	1054.8	391.77	359.75	254.15
9	1581.7	587.6	539.5	281.23
11	2108.5	783.42	719.43	508.31
13	2635.4	972.24	899.27	635.39
15	3162.2	1175.1	1079.1	762.46
17	3689	1370.9	1259	889.54
19	4215.9	1566.7	1438.8	1016.6
21	4742.7	1762.5	1618.6	1143.7
23	5269.6	1958.4	1798.5	1270.8
25	5796.4	2154.2	1978.3	1397.9
27	6323.3	2350	2158.2	1524.9
29	6904.94	2545.8	2338	1652
30	7444.84	2741.6	2517.8	1779.1

The uneven heat distribution for stainless steel could pose performance glitches as this means that only the outer circle has expanded, and inner radius remained almost in original state. The results for mild steel and gray cast iron are similar in performance even though the maximum heat flux for mild steel is higher. The differential heat flux between inner and out radius for grey cast iron is lower as opposed to mild steel. There was a clear connection between the highest values of the actual friction force and the temperature, the longer the time the maximum temperature levels are reached, the longer the time the maximum heat stream strength occurs (Yevtushenko et al, 2019). Thermal conductivity of any material is a function of its heat conduction capacity. Thermal conduction is the transition of intrinsic energy within a body through microscopic particle interactions and the migration of electrons. Particles that encounter, including gases, atoms and electrons, transfer disorganized microscopic kinetic and potential energy, generally known as internal energy (Yevtushenko et al, 2014).

The contribution of heat flux in disc material is due to specific heat value for each disc material. From the analysis it is noted that aluminium recorded the highest heat flux as a results of high specific heat capacity of 875 (J/Kg/C), which is higher than all the other disc material. Heat flux can be simplified as the heat generated per second per unit area applied to material as demonstrated in Equation 2.

5. Conclusion

This paper investigated the numerical analysis of the brake disk for a practical finite element model with the application of ANSYS software. The effects of natural frequency vibrations in specific and four material were numerically analyzed. The results obtained are based on investigations completed based on the thermal temperature and heat flux analysis. Considering the similarity in results favorable for mild steel, we can conclude that mild steel is a better material of all the four initially chosen material. Based on the parameter given and data, mild steel is the best material for designing the conveyors disc brake. Mild steel can accommodate a lot more temperature is it has high capability and resistive to heat flux.

In conclusion, comparing all four results from the analysis it can be decided that mild steel and grey cast iron are more favorable material however because grey cast iron is a lot more expensive, mild steel will then be the preferred and chosen material for conveyor belt brake application. As far as the measured results are concerned, it can be concluded that they are accurate and in line with the literature. In order to demonstrate an agreement of model with practical analysis, an experimental study on a test bench is required to be done.

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Reference

Aleksendric, D., *et al.* (2008) 'Intelligent control of disc brake operation', *SAE Technical Papers*, (October 2008).

Belhocine, A., *et al.* (2012) 'Thermal analysis of a solid brake disc', *Applied Thermal Engineering*, 32(1), pp. 59–67. doi: 10.1016/j.applthermaleng.2011.08.029.

Belhocine, A., *et al* (2014) *Structural and thermal analysis of automotive disc brake rotor*, *Archive of Mechanical Engineering*. doi: 10.2478/meceng-2014-0005.

Cho, C., *et al.* (2014) 'Thermal analysis of ventilated and full disc brake rotors with frictional heat generation', *Applied and Computational Mechanics*, Volume 8, p. pp 5-24.

Daoming, W., *et al.* (2011) 'Temperature Field Study of Brake Disc in a Belt Conveyor Brake', *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, 5(12), pp. 2665–2668.

Deekshith, C., *et al.* (2017) 'Design, Analysis and Manufacturing of Disc Brake Rotor', *International Journal Of Engineering Research And Development e*, 13(11), pp. 15–23.

Dhakar, P. S. (2016) 'Thermal Analysis of Disc Brake Using Ansys Software', *International Journal of Advance Engineering and Research Development*, 3(03).

Fangwei, X., *et al.* (2011) 'Control strategy of disc braking systems for downward belt conveyors', *Mining Science and Technology*, 21(4), pp. 491–494.

Gezes, P. (2019) 'Maximum temperature of the disc during repeated braking applications', in Shun-Peng Zhu (ed.) *Advances in Mechanical Engineering*, pp. 1–13.

Ghadimi, B., *et al.* (2013) 'Thermal analysis of locomotive wheel-mounted brake disc', *Applied Thermal Engineering*. Elsevier Ltd, 51(1–2), pp. 948–952.

He, D. *et al.* (2018) 'Healthy speed control of belt conveyors on conveying bulk materials', *Powder Technology*. Elsevier B.V., 327, pp. 408–419.

Islahi, A., *et al.* (2017) *Thermo-Mechanical Analysis of Automotive Disc Brake Composite Rotor*.

Jaiswal, R. *et al.* (2016) 'Structural and thermal analysis of disc brake using solidworks and ansys', *International Journal of Mechanical Engineering and Technology*, 7(1), pp. 67–77.

Lodewijks, G., *et al* (2016) 'Determination of Acceleration for Belt Conveyor Speed Control in Transient Operation', *International Journal of Engineering and Technology*, 8(3), pp. 206–211.

Nouby, M., *et al.* 'Thermal Modeling of Disc Brake Rotor in Frictional Contact', *Journal of Multiscale Modelling*, 05(03), p. 1350013.

Talati, F, *et al.* (2009) 'Analysis of heat conduction in a disk brake system', *Heat and Mass Transfer/Waerme- und Stoffuebertragung*, 45(8), pp. 1047–1059.

Yakout, M., *et al.* (2018) 'A study of thermal expansion coefficients and microstructure during selective laser melting of Invar 36 and stainless steel 316L', *Additive Manufacturing*. Elsevier, 24(August), pp. 405–418.

Yevtushenko, A.A., *et al.* (2014) 'Temperature in thermally nonlinear pad-disk brake system', *International Communications in Heat and Mass Transfer*. Elsevier Ltd, 57, pp. 274–281.

Yevtushenko, A., *et al.* (2019) 'Effect of the temporal profile of the friction power on temperature of a pad-disc brake system', *Journal of Theoretical and Applied Mechanics*, 57(2), pp. 461–473.

Youfu, H., *et al.* (2011) 'Temperature Field Study of Brake Disc in a Belt Conveyor Brake', *World Academy of Science, Engineering and Technology International Journal of Mechanical and Mechatronics Engineering*, 5(12), pp. 2009–2012.

8. Biographies

Daniel Chelopo is an Associate Bulk Material Handling Engineer for Aurecon Group of consultants in South Africa. Daniel obtained a Bachelor of Technology in Mechanical Engineering from University of Johannesburg (UJ), South Africa, in 2008 and a National Diploma in Mechanical Engineering from the Technikon Witwatersrand (TWR), South Africa, in 2000. Daniel holds a Diploma in Designs and Operations of Belt Conveyors from the Conveyor Manufacturing's Association of South Africa and a Certificate of Competency in Belt Conveying of Bulk Solids from Wits University. He is a member of the South African Institute of Mechanical Engineering (SAIMechE) and registered as professional engineering technologist with the Engineering Council of South Africa (ECSA). He is a qualified mechanical engineer with more than 19 years of experience in industrial and multi-disciplinary engineering management. He has worked on projects in South Africa; Mozambique; Botswana; Ireland; Sweden and Namibia, where he was responsible for providing industrial technical support; mining equipment supplies and equipment refurbishment

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