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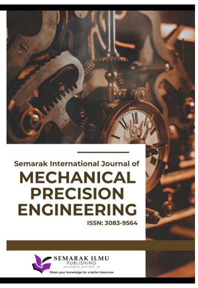

Hazard Identification and Failure Analysis in Grinding Process

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ABSTRACT

The grinding process is a material removal technique to shape and refine various materials. By using an abrasive wheel, flat or cylindrical surfaces can be shaped and often used as a finishing process in product making. However, the process has the potential to cause serious harm if handled inappropriately specifically with regards to the rotating abrasive wheel. This work aims to identify and analyse the root causes leading to grinding process failures. It involves a review of relevant literature on accidents and potential hazards. Next, the information was clustered by using an affinity diagram and the category with the highest frequency was selected which is ergonomics. After that, hazard identification and risk assessment were conducted on the ergonomics category to identify the activity with the highest risk. Strengths, weaknesses, opportunities and threats or SWOT analysis was utilized to select the most significant activity to be simulated. The design was created by using SpaceClaim software and the simulation was analysed by using ANSYS software. Through the simulation, it was found that at normal grinding force of 1800 N, the deformation is 0.0045 mm and the equivalent (von Mises) stress is 26.3160 MPa. The findings help to promote a safe working condition and the appropriate use of grinding equipment especially when there is contact with rotating parts.

1. Introduction

The grinding process is a manufacturing technique used to precisely shape and finish the surfaces of materials. It involves the use of abrasives, such as grinding wheels to remove material from a work piece to achieve the desired shape, size, and surface finish. When grinding, the work piece is usually kept in place while the high-speed revolving grinding wheel abrasively eliminates tiny material pieces. Tight tolerances and smooth surface finishes are possible with this method [1]. Example of the applications are surface finishing, material removal, sharpening tools, and achieving precise dimensions [2,3].

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In the grinding process, cutting happens when the abrasive grains on the wheel chip away material by penetrating the work piece. Plowing occurs when the grains push or deform the material without effective cutting, and rubbing is when the wheel slides on the surface without removing much material, often due to factors like inadequate pressure or inappropriate wheel characteristics. Potential failures can arise, including thermal damage to the work piece due to excessive heat generation, wear and loss of precision in the abrasive wheel, and integrity issues like surface cracks or metallurgical changes in the material being ground [4].

A portion of the grain may wear throughout the wheel's life cycle because of both fracture and erosion. Bond fracture is the complete breakout of the grains in more severe or extreme situations. Broken grinding wheels are a common mechanical failure that can cause shards to eject at high speeds and cause serious injury. Wheel breakage can be caused by poor attachment, high speeds, and manufacturing errors. While grinding, work pieces or debris may be expelled, posing serious dangers to operators [5]. Ergonomic strains can cause operator attentiveness to be reduced, which can result in mishandling and accidents, while high-speed operations can ruin grinding wheels. Using an abrasive grinding wheel to remove material from a work piece, some other hazards include malfunctioning grinding wheels, excessive loads, and unsecured machinery [6,7]. A thorough failure analysis strategy, encompassing root cause analysis, and failure modes and impacts analysis, is necessary to address these issues. To effectively mitigate these risks, it is crucial to simulate the safe working conditions and prevent potential machine failures.

Hazard identification and risk assessment is a methodical process that is used to identify possible risks and evaluate the risks connected to those risks. The analysis is conducted to reduce the risks of hazards. It is an essential tool for managing workplace safety and health [8]. This entails determining possible risks, evaluating the hazards, and putting in place suitable countermeasures [9]. Numerous reasons, including vibrations, heat damage, and high grinding forces, can lead to grinding wheel failure. Normal grinding force is about 1800 N [3,10]. Managing the grinding forces is crucial to prevent grinding wheel failure.

To investigate the interaction between abrasive grains and the work piece surface Zahedi and Azarhoushang [11] used a finite element method (FEM) model. With a suitable technique that included a kinematics model and a probability density function for the location of abrasive grains, a single-grain model was used to forecast the work piece surface. Nadolny *et al.,* [12] created a topography model of grinding wheels and how it interacts with the surface of the work piece which may be used to design new wheel types and lower the cost of developing new wheels. Zhang *et al.,* [13] constructed a grinding wheel model with abrasive grains arranged at random and examined the behaviors of the grains in contact with the work piece as well as the evolution of grinding forces. These findings show that simulation analysis helps find the output of the failure analysis which is total deformation and equivalent (von Mises) stress. ANSYS simulations are widely used by industries that need to perform static calculations to solve both linear and non-linear problems when it comes to structures, heat transfer and fluid dynamics, as well as acoustic and electromagnetic issues [14].

The grinding process operates with rotating wheel having potential hazards such as malfunctioning of grinding wheels, expelled of debris causing danger to operators or mishandling. Therefore, this project aims to identify the hazards related to the grinding process, analyze the most significant problem and simulate the event at the normal grinding force to prevent grinding failure.

2. Methodology
2.1 Hazard Identification

The work started by identifying the reported accidents and literature related to failures and hazards during grinding activity. The information was obtained through a desktop study. Then, by using an affinity diagram the information was clustered. The findings were classified into four categories namely ergonomics, improper grinding parameters, faulty electrical systems and chemical risks. From the affinity diagram, the frequency of occurrence was analyzed, and information was translated into a pie chart.

Out of the four categories, the highest occurrence of failures and hazards was selected. Then, hazard identification and risk analysis were done. By using SWOT analysis, strengths, weaknesses, opportunities and threats of the activity with the highest risk were conducted. Finally, a simulation was done to understand the reason how and why the process failed.

2.2 Simulation of Hazard

SpaceClaim software was used to design the grinding wheel and the work piece. The dimension of the grinding wheel is 150 mm for radius, inner diameter of 30 mm and 20 mm thickness. The work piece is 246 mm long, 60 mm wide and 10 mm thick. Then, the design was exported to ANSYS software to be simulated. The meshing is done with quadrilateral elements in both geometries, grinding wheel and work piece with 9895 elements and 20458 nodes as in Figure 1. The simulation employed force, fixed support, remote displacement; the boundary and the loading conditions are shown in Table 1.

The values for each loading condition and boundary condition are as follows: a varying force gradually increased until it exceeded 1800 N. Fixed support was used to constrain specific areas of the grinding wheel and remote displacement was defined to imitate the relative movement of the wheel. These prerequisites were essential for simulating the grinding wheel's actual operating environment. From the analysis, the equivalent (von Mises) stress and total deformation can be obtained. From the analysis, the total deformation and equivalent (von Mises) stress at normal grinding force can be found.

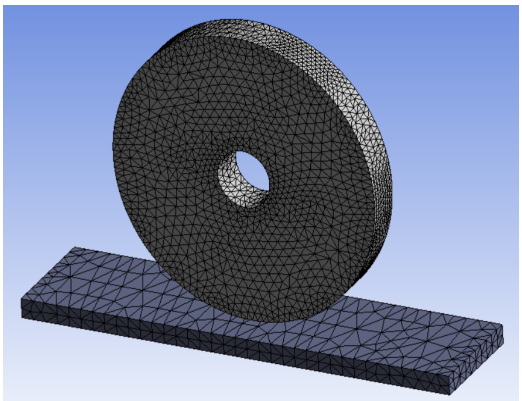
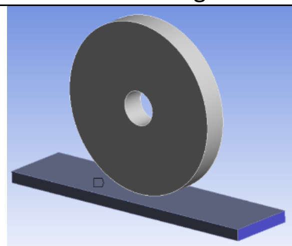
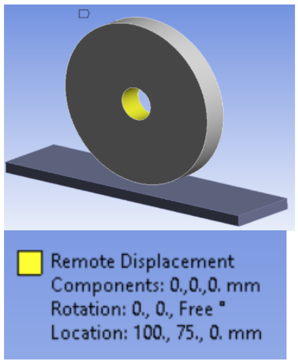
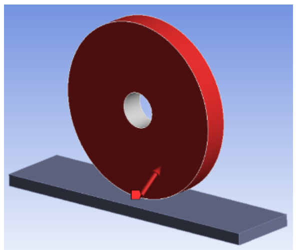


Fig. 1. Quadrilateral meshing of grinding wheel and work piece

Validation of total deformation and equivalent (von Mises) stress is made with the work established by Sharad *et al.,* [15]. The percentage of errors is calculated by using Eq. (1). Finally, in identifying the total deformation and equivalent (von Mises) stress at normal grinding force, simulation was done with increment starting from 123.22 N to 2384.40 N.

$$\text{Percentage Error} = \frac{\text{Observed Value} - \text{True Value}}{\text{True Value}} \times 100 \quad (1)$$

Table 1
Boundary and loading conditions for the grinding wheel simulation

Boundary conditions	Geometry	Values	Location and Image
Fixed support	Work piece	Located at the bottom of the work piece	
Remote displacement	Grinding wheel	Components • X = 0 mm • Y = 0 mm • Z = 0mm Rotation • X = 0 • Y = 0 • Z = Free Location • Axis X = 100 mm • Axis Y = 75 mm • Axis Z = 0 mm	
Loading condition	**Geometry**	**Values**	**Location and Image**
Force	Grinding Wheel	Magnitude of Force (N) • 123.22 N to 2384.40 N	

3. Results and Discussion
3.1 Hazard Identification and Analysis
3.1.1 Affinity diagram

Through desktop study, published manuscripts and news related to hazards and accidents in the grinding process were listed. Then, the findings were classified into similar conditions. A name is selected for every category namely ergonomics, improper grinding parameters, faulty electrical systems, and chemical risks by using an affinity diagram as shown in Table 2.

3.1.2 Hazard identification and risk assessment

Based on the list of findings and the overall frequency of hazards presented in Table 2, an analysis of hazards caused by the grinding process was conducted. The information was translated into a pie chart in Figure 2. It was found that ergonomics hazard is the highest. These elements influence operational effectiveness and productivity in addition to worker health and safety which can result in worker absences, lower productivity, and possible safety issues [16].

Table 2
Hazard classifications using an affinity diagram

Category	Hazards	
Ergonomics	i)	Materials or tools that are not properly organized or secured in the grinding area.
	ii)	Inadvertently encounter rotating parts of the grinding machine, such as the grinding wheel or spindle.
	iii)	Structural elements of the grinder, the workshop and equipment.
	iv)	Dirty windowpanes, missing or wrong light sources, wrong light fixtures.
	v)	Lifting or turning of work pieces, grinding wheels or tooling elements.
Improper Grinding Parameters	i)	Microchips sprinkle from the grinding zone due to materials with high hardness or brittleness.
	ii)	Control and adjustment of parameters such as spindle speed, feed rate, and depth of cut to achieve the desired material removal rate, surface finish, and dimensional accuracy.
	iii)	Hot surfaces of work pieces, due to contact between the rotating grinding wheel and the work piece generate frictional heat.
	iv)	Selecting, positioning, and securing the polishing stone onto the grinder machine's spindle or arbor, ensuring proper alignment and stability.
	v)	Installations and electrical equipment, including the sources of local lighting. Damaged insulation of cables. Contact with the machine's metal casing which can be under voltage.
Faulty Electrical Systems	i)	Faulty electrical systems, use of open flames near flammable and explosive materials or coolant.
	ii)	The grinding process, the grinder's power transmission system and machine tools used at the adjacent positions.
Chemical Risks	i)	Inhalation of copper powder.
	ii)	Application of the coolant to the grinding zone.
	iii)	Cleaning of materials to remove coolant residue.
	iv)	Recycling grinding sludge by separating metal fines from coolant and reusing both components.

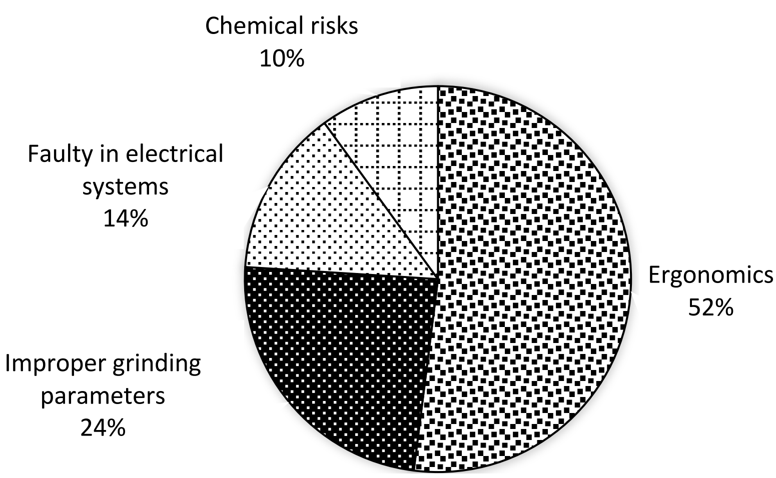


Fig. 2. Analysis of hazards caused by the grinding process

Following that, a risk assessment was conducted for all findings in ergonomics hazards. The risk assessment considers the risks' likelihood and severity ratings. The higher the rating of multiplication of both categories represents the higher the risk of the activity. The analysis was conducted based on the guidelines provided by the Department of Safety and Health, Malaysia [17]. Table 3 shows the hazard identification and risk analysis for ergonomics hazards. All hazards are at high risk except for two; structural elements of the grinder, the workshop and equipment and lifting heavy load.

Table 3
Hazard identification and risk analysis for ergonomics hazard

Hazard identification				Risk analysis		
No.	Activity/ Description	Hazard	Effect/ Information	Likelihood	Severity	Risk
1.	Materials or tools that are not properly organized or secured in the grinding area.	Unorganized tools	Tripping hazards for workers, especially in busy work areas.	3	5	15 (High)
2.	Inadvertently encounter rotating parts of the grinding machine, such as the grinding wheel or spindle.	Contact with rotating parts of the grinding machine	The abrasive nature of the grinding wheel can lead to deep cuts or severe abrasions.	3	5	15 (High)
3.	Structural elements of the grinder, the workshop and equipment.	The structural element of the grinder	The worker suffered a severe laceration and crush injury to the hand.	2	5	10 (Medium)
4.	Poor lighting while conducting the grinding process.	Dirty windowpanes, missing or wrong light sources, wrong light fixtures.	Potentially resulting in injury to the operator's hand due to decreased visibility.	3	5	15 (High)
5.	Lifting a heavy load or turning work pieces, grinding wheels or tooling elements improperly.	Lifting of work pieces, grinding wheels or tooling elements.	Causing a worker to strain their back or potentially leading to injuries to themselves.	2	5	10 (High)

3.1.3 Risk control

Potential risk control for the listed hazards in Table 3 are as follows:

i) Unorganized tools – To maintain clean and organized workplace by implementing 5S principles (sort, set in order, shine, standardize, sustain) and established specific storage locations to prevent clutter and accident.
ii) Contact with rotating parts of the grinding machine – To install guard in rotating parts area and provide comprehensive training to operators on safe operating procedures.
iii) The structural element of the grinder – To conduct regular maintenance schedule to ensure the equipment is in good condition and address any potential structural defects.
iv) Dirty windowpanes, missing or wrong light sources, wrong light fixtures – To clean the window, to provide sufficient illumination in the grinding area by installing appropriate lighting fixtures or rearranging the machine position.
v) Lifting of work pieces, grinding wheels or tooling elements – To train operators on proper lifting techniques and to use mechanical aids to lift heavy loads such as hoist

Out of the five hazards, contact with rotating parts of the grinding machine is one of the high risk hazard and was selected to be further investigated. SWOT analysis was utilized to assist in the decision-making. The SWOT analysis of rotating parts of the grinding machine is given in Table 4.

Table 4
SWOT analysis of contact with the rotating part

Strengths	Weaknesses
i) Hazard with rotating part requires immediate action as it can lead to severe injuries. ii) Detail investigation and analysis enable data-driven decision-making.	i) The hazard activity does not include information about the impact or severity of each hazard, only frequency data. ii) Lacking details regarding the circumstances or situations that give rise to these risks.
Opportunities	**Threats**
i) As it has higher frequency of occurrence, safety procedures can be enhanced and lessen the likelihood of common dangers. ii) Leverage new technologies and enhance training programs.	i) Possible changes in standards or regulations may increase compliance costs or operational challenges. ii) Modification of the current standards or regulations can introduce new hazards.

3.2 Simulation of Hazard
3.2.1 Simulation of grinding process

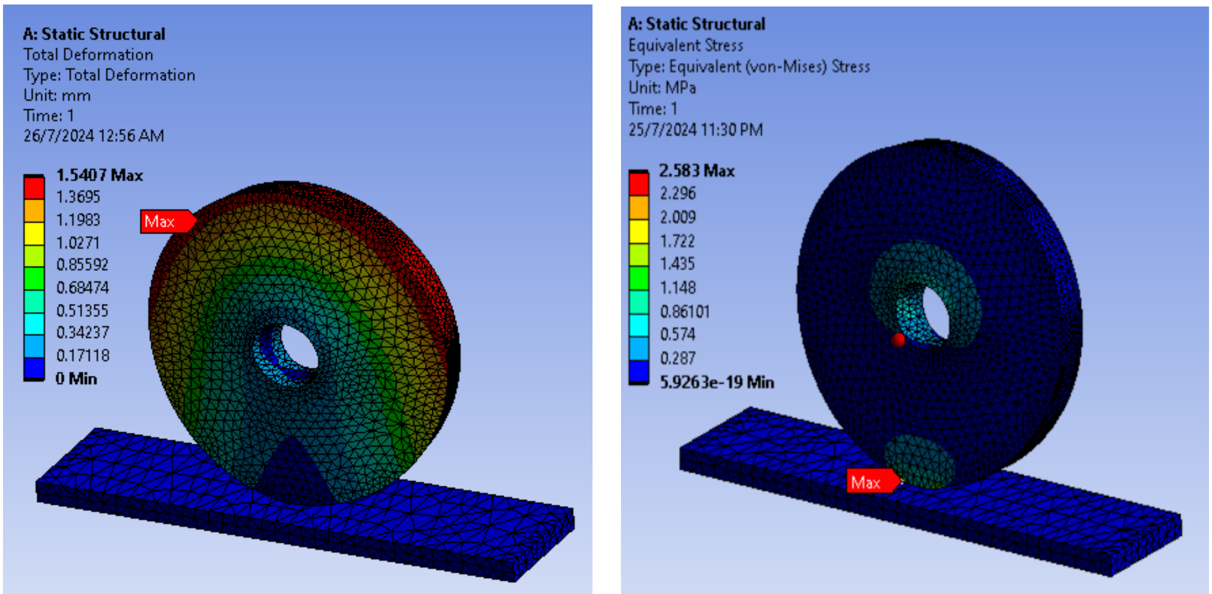
In the ANSYS model of the grinding process, total deformation is an indicator of strength and accuracy in machining. This measurement shows the displacement and strain the work piece and grinding wheel experienced when grinding forces are applied. Total deformation is the vector sum of all directional displacements of the systems [14]. Figure 3(a) shows the total deformation is 1.5407 mm, located at the top of the grinding wheel. The rotational motion and the distribution of grinding forces are two of the elements that cause the total deformation at the top of a grinding wheel. The wheel experiences the most deformation near its outer edge when it turns because there is a greater centrifugal force there as well as the highest tangential velocity. Furthermore, strong normal forces are applied to the wheel's surface during the grinding operation, which contributes to deformation at the top [18]. This deformation information can give understanding to improve grinding parameters, make better material selections, and guarantee the dependability and security of the grinding process [19].

The equivalent (von Mises) stress of the simulation is given in Figure 3(b). This is an indicator of possible material failure or work piece deformation in the ANSYS grinding process simulation. The highest value of the equivalent (von Mises) stress is 2.5830 MPa which is located near the grinding wheel and work piece surface.

3.2.2 Validation of the grinding simulation

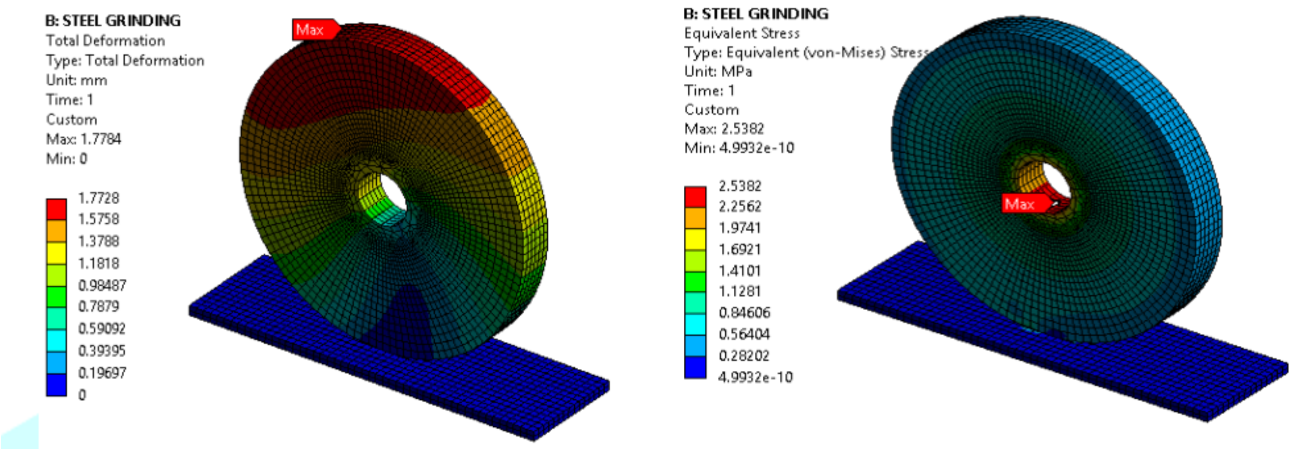
To validate that simulation forecasts are accurate, the work must be compared to established benchmarks. Differences between the reported findings and the published work could be explained by the sensitivity of simulation results to several parameters, including mesh density, material properties, boundary conditions, contact algorithms, and load application techniques. A comparison of this work is made with work done by Sharad et. al [14].

By using Eq. (1), the comparison of total deformation exhibits a 13.09% error. The difference is due to the element type selection which is hex dominant and tetrahedrons. Different elements work better in different situations, which affect the distribution and identification of deformation. In the case of the value of the equivalent (von Mises) stress, the error is 1.77%. Both validations can be observed in Figure 4.



(a) (b)

Fig. 3. (a) Total deformation of grinding wheel and workpiece (b) Equivalent (von Misses) stress of grinding wheel and workpiece



(a) (b)

Fig. 4. Validation on (a) Total deformation of grinding wheel and work piece (b) Equivalent (von Misses) stress of grinding wheel and work piece

3.2.3 Analysis of results

During the grinding process, the cutting force and the friction force are added together to form the grinding force. This force affects how the grinding process is formulated and how much damage is done to the subsurface and grinding surface. The simulation was done with force, starting from 123.22 N to 2384.40 N to find the deformation and equivalent (von Mises) at a normal force of 1800 N to the grinding wheel [3.10]. Usually, the improper transitions in phase, heat treatment, and erosion are the causes of problems in the metallurgical failure category which is considered as the reasons why the grinding wheel starts to fail [20].

Figure 5 shows the relationship between total deformation and equivalent (von Mises) stress against the applied force. When the applied force increases, the total deformation generally shows an increasing trend. Equivalent stress also increases with applied force. At 1800 N, the deformation is 0.0045 mm and the equivalent (von Mises) stress is 26.3160 MPa.

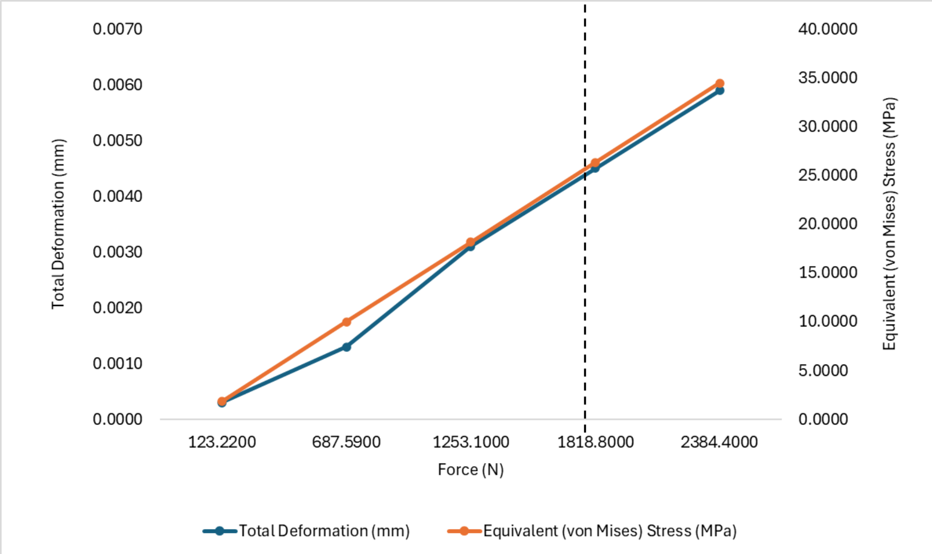


Fig. 5. Total deformation and equivalent (von Mises) stress vs. applied force

4. Conclusions

This work reviewed published work and news related to hazards in the grinding process. Through the affinity diagram, hazard identification and SWOT analysis, the most significant hazard was identified. Later, the hazard condition was simulated by using ANSYS. The simulation was validated with published work. It was found that at normal grinding force of 1800N, the deformation is 0.0045 mm and the equivalent (von Mises) stress is 26.3160 MPa. The work allows an understanding of the safe working condition when regular grinding process is taking place. Later, investigation on maximum force that leads to potential failure in grinding will be simulated. This will highlight the appropriate use of grinding equipment and indirectly helps to reduce risk of accidents.

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