

Original Research Paper

Tribological Performance of Materials Under Bio-Three Body Abrasion

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Abstract: This study aims to investigate the effects of seed grinding process on the tribological characteristics of components in agricultural machines. The objective is to conduct the the effect of third body presence such as seeds on the tribological behavior of agriculture machines and evaluate the fracture mechanism of the seeds under three body abrasion loading conditions. The work consists of two main parts: Firstly, mechanical test which is related with the *Hounsfield* compression machines test and understanding the mechanical behaviour of wheat seed (*Triticum aestivum*) under compressive loading conditions. Secondly, the research aim to modify the current tribology machine to perform three body abrasion owing to test the rubbed components under seed third body configuration. Moreover, for each grind attempt, different discs have been used such as; the rubber disc, mild steel disc and stainless steel. The mechanical results revealed that the samples have maximum forces need to breakdown (rapture) the seed was (125 N) and minimum (84 N) average for all samples (102 N), stress results were maximum (1.81 Mpa), minimum (1.26 Mpa), average for all samples (1.58 Mpa) and in regarding to elongation average result was (0.86 mm). The failure mechanism was clear fracture in the seeds due to the brittleness behaviour of the seed and splitting of the seeds into two halves is the obvious damage feature. For the tribology machine, different attempts have been used to modify the machine to conduct the three-body abrasion for the grindings the seeds. However, there is no attempt displayed a good result. Grinding process for wheat seed by using rubber disc exhibited no result comes out because the seeds surfaces' tribological properties cannot affect the rubber surface and both have the same smoothness surfaces. In another word, the seed shape is not multi-angles or has not brittle shape (nature) to provide better contact with rubber disc. Secondly with applying mild steel for grinding the same result find out the seed cannot grinding because the disc tribological still cannot supply best condition to crush seed might be this issue related with the shape of wheat seed also which is ellipse shape and the steel is highly smoothed. Therefore, both disc and seed are circle shape that is making them rotating each other's rather than effect surface each other. Finally, the modification has been done for the tribo-machine enhancing the grinding operation. The modification was putting gear under the mild steel disc. This strategy helps the process quite successfully.

Keywords: Tribology, Three Body Abrasion, Polymer Machines

Introduction

In recent years, there has been an increasing focus towards tribological awareness which has happened in agricultural machines components particularly in grain grinding industries (Baker, 2014; Bello *et al.*, 2015). This attitude has seen an emergence in occurrence of environmentally and friendly, sustainable tribological characteristics. The grinding operations have benefited public in many different sectors. Recently, there has been increasing concerns over the applying the grinding and milling operations in flour and even mining industries (Beerling *et al.*, 2018; Miskelly and Suter, 2017). A genuine concern is the increase cost for repair deformed and replacement components. There is a requirement to find a sustainable way to avoid failure in fracture surfaces (Ijomah *et al.*, 2007). For this reason, testing and evaluating material tribological and mechanical properties are key factor to estimate these issues around them (Bai *et al.*, 2019; Bazgari *et al.*, 2018). Crusher and miller are crucial part of machines for preparation of agricultural food industry (Al-Sandooq *et al.*, 2012). Currently, milling machines are used to crush wheat, sorghum and soybean that they can be used as animal food especially (cattle and poultry) (Hachmeister and Fung, 1993). The miller or crusher are designed differently to provide multifunctional jobs whether it cylindrical steel roller or two flat surface. Also, according to (Al-Sandooq *et al.*, 2012) polymers could replace steel in agricultural machines components. In conclusion, it is a sensitive gap in this discipline for finding optimization alternative solution.

Presently, there has been an increasing focus towards tribological responsiveness which has happened in

agricultural machines components particularly in grain grinding industry (Findik, 2014). Also most of the machines are not deformed however the only reason seat and tear or tribological characteristic are the main issue to occur breakdown the machines parts. Nowadays there has been increasing concerns over the abrasive or surface fracture failure among materials. There is a gap of research on understanding the three-body abrasion in agriculture machine.

Materials and Procedures

Firstly, mechanical test conducted under compressive loading condition by putting single wheat seed between two loads after measuring the seed dimensions. For this part, the four random wheat seed (*Triticum aestivum*) have been selected and measured. Wheat seeds (*Triticum aestivum*) in 20 kilograms has been supplied by Toowoomba Core Company, in Australia. Figure 1 illustrates four single wheat sample which, have been selected randomly for measuring their dimensions (length, width and height) the average of each dimensions with semi-axes are length 6.5625 mm, width 3.3675 mm and height 3.175 mm.

Figure 1 demonstrates the finding area of the seed by assuming the seed shape as ellipse shape which, the equation is: Area of ellipse = ($\pi * a * b$), $\pi = (3.14)$ and A= bigger diameter B = lower diameter. Figure 2 clarify measuring seed dimensions. Four single seeds were selected randomly. Measuring the dimension is important to find out the surface area of the seeds this measured can be done by two most accurate ways which is (1) *Vernier Caliper* and (2) under the microscopy.

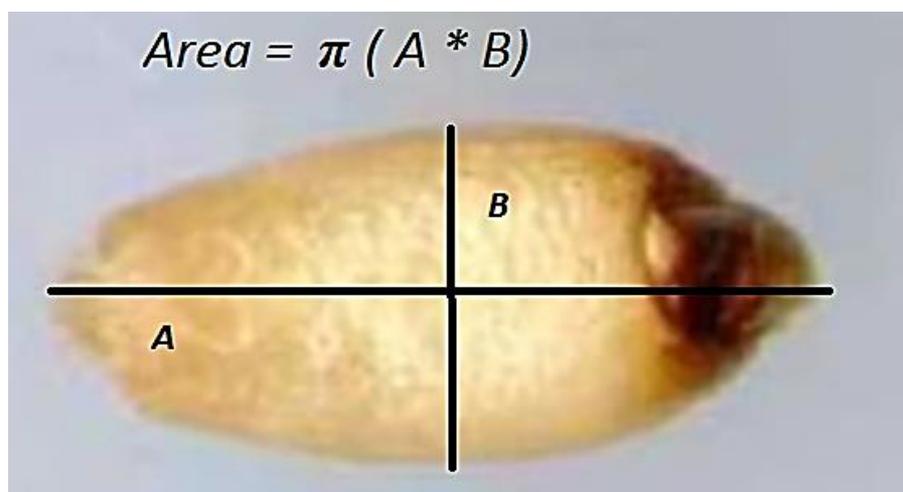


Fig. 1: Area of wheat

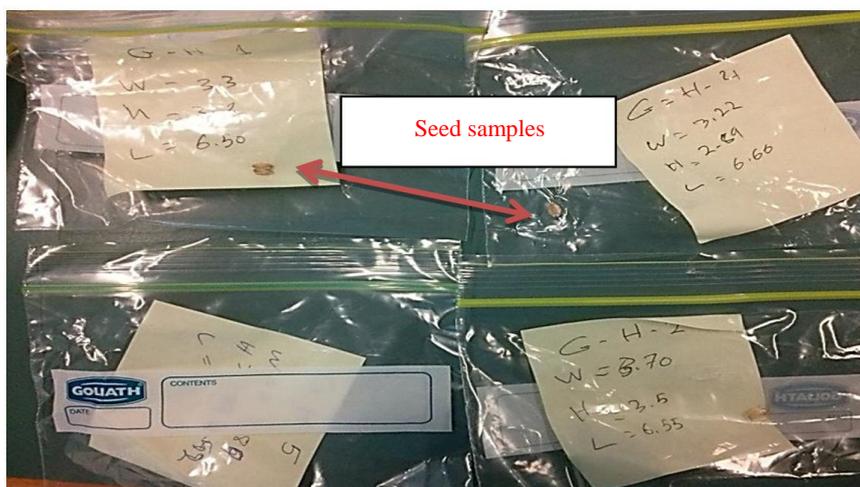


Fig. 2: Sample preparation of wheat seed

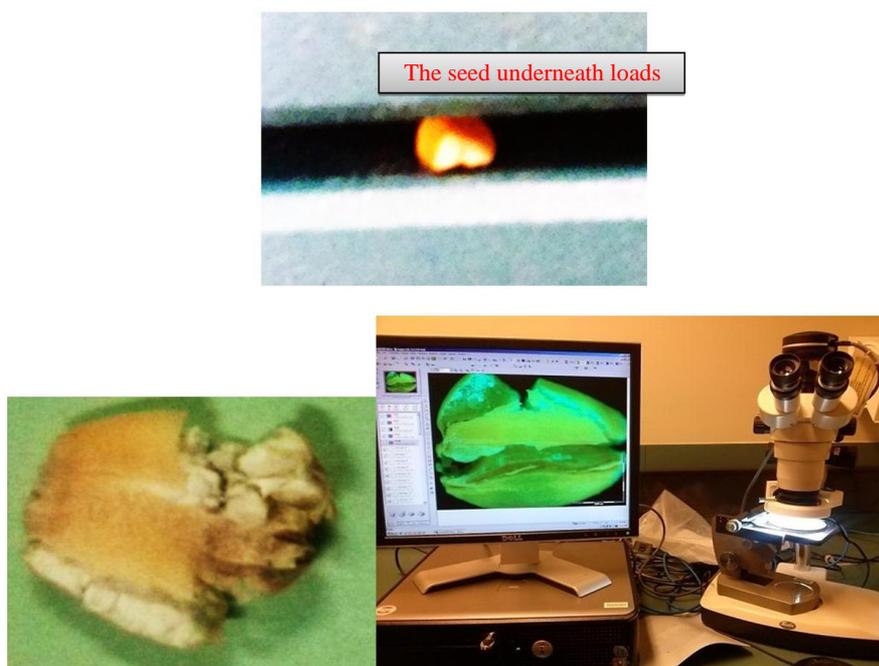


Fig. 3: Single wheat seed tested and examined using optical microscopy

Experimental Setups

A universal tensile testing machine with capacity of 10 kN was used in the compressive testing. The machine connected with computer which can present the fracture point and break point via data system. The tests were conducted at load rate of 1 mm/min. After each test, the fractured seed was examined using optical microscopy to examine to identify the loading points.

The whole system of Hounsfield compression machine test consists of three main parts firstly, is loads (head load and bottom load). This part can be adjusted both manually and automatically via the computer. Second key part the

machines control board to calibrate the requirements. Figure 3 displays the seed between the two compressive flat surfaces of the head and bottom plats of the machine.

With regards of the tribological experiments, tribology machine with block on ring configuration was used. Wheat seed (*Triticum aestivum*) has been grinded by tribo- machine running under three body abrasion (3BA) mode with different applied loads (10, 15 and 20 N) and speeds (50, 200, 500, 750 and 1000 rpm). For each test, the rubber disc, mild steel disc and mild steel with steel gear were polished using 1200 grade sand papers. Moreover, optical microscopy was used to examine the fracture of the seeds.

Results and Discussion

Figure 4 displays the principle of working and compressing the seed underneath two loads. It demonstrates both rupture and fracture point practically. It can be seen that the seed has been compressed and the two remain place that initially effected because these two pint are in highest place compare to other places due to the ellipse shape of the seeds. The figure demonstrates the dimensions of the seed owing to determine the area

under the microscopy that gives accurate result as annotated and highlighted with red line. the optical microscopy can determine the area of ellipse. In addition, the area can be determined using the area of ellipse = $\pi * a * b / 4$

Where:

a = Bigger diameter (width)

b = Lower diameter (height)

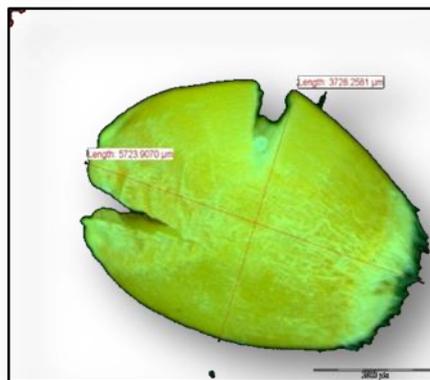
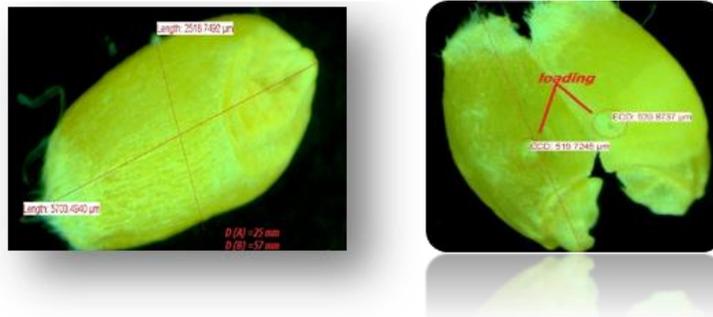
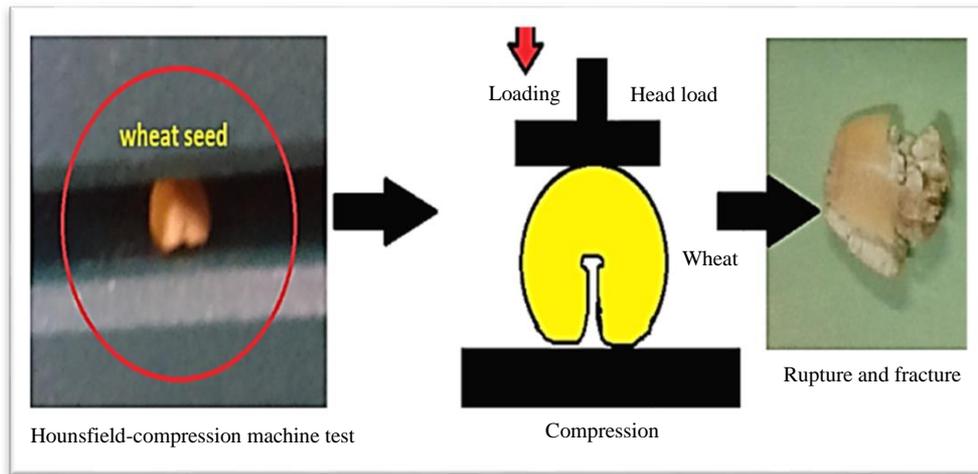


Fig. 4: Rapture and breakdown fracture point

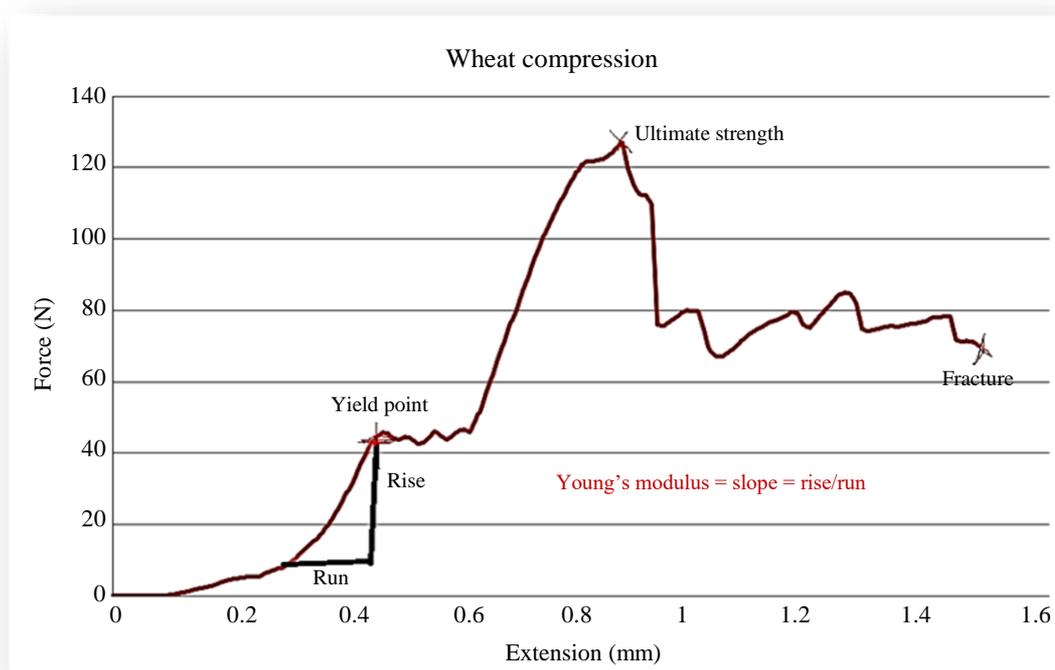


Fig. 5: Seed compression stages

Table 1: Seed dimensions

The seed sample	Length(mm)	Width(mm)	Height (mm)	Area of seed (mm ²)
1	6.8000	3.4500	2.910	16.50
2	6.5500	3.7000	3.500	14.23
3	6.7000	3.1000	3.400	15.56
4	6.2000	3.2200	2.890	15.00
Average	6.5625	3.3675	3.175	16.10

Figure 5 illustrates the measuring of fractured seed under the microscopy that is can give very accurate result as annotated and highlighted with red line.

Table 1 represent the measured dimensions of four seeds. Area of the four seeds were determined and the average was calculated. There is some variation can be seen which is expected since there is no identical two seeds. The average area will be used to determine the stress on the seed:

$$e = \frac{\Delta L}{L} = \frac{\ell - L}{L}$$

Where:

e = Delta L/L = 1-L/L

ΔL = Change in length

e = Is the engineering normal strain

L = is the original length

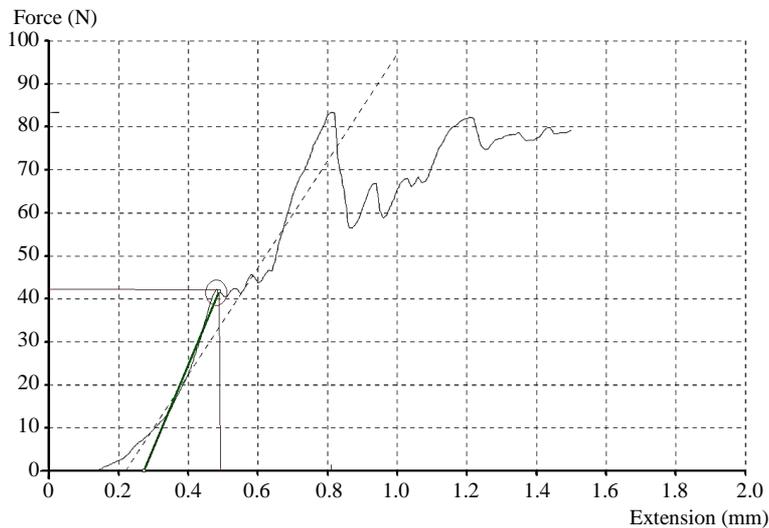
ℓ = Is the final length

(Stress = force/area)

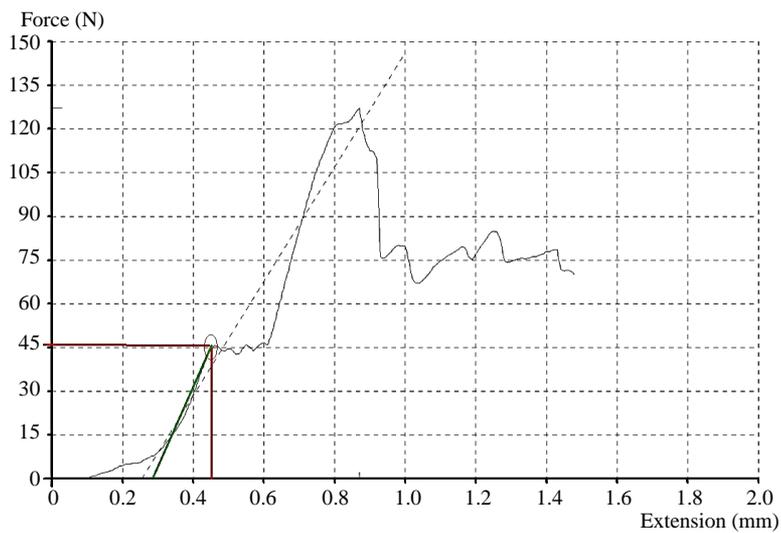
(Strain = elongation/thickness)

Note: Thickness can be assumed instead of average of both large and small diameters because it has been assumed that wheat seed shape is ellipse.

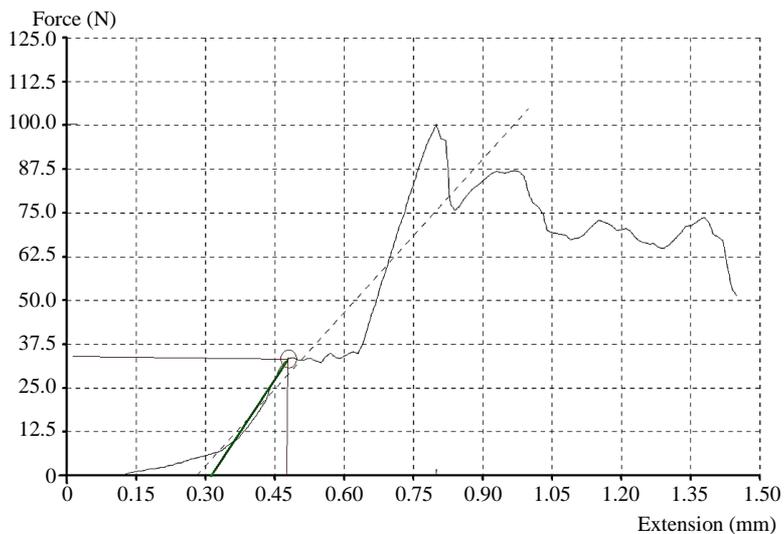
Sample of the compression test is presented in Fig. 4 to displays the phases of the test. The figure shows that there are three main phases in the test. The first stage was interaction of the flat heat of the force onto the surface of the seeds since there is fluctuation in the force and there is no much increase in the force despite there is high elongation. In the second stage, an elastic region can be seen since there is linear relation of the force vs. elongation. At this stage, the modules of elasticity can be determined by the known formula of stress/strain. At the end of that stage, yielding point can be seen and after that there is no much increase in the force which indicate the failure of seed. Increase in the force afterward should not be count since it is crashing process rather than compressive process. The details of the compressive testing for each seed is presented in Fig. 6.



(a)



(b)



(c)

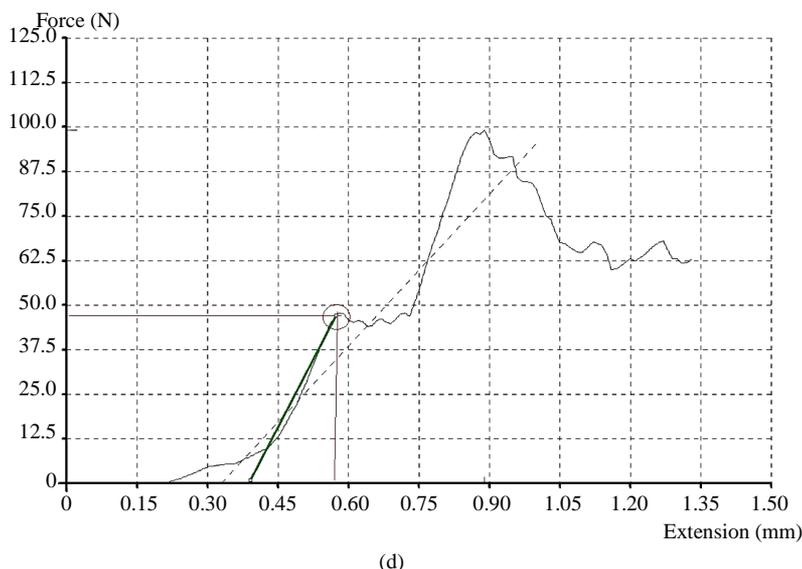


Fig. 6: Force vs. elongation of difference samples; (a) First sample (elongation and rupture point); (b) Second sample (elongation and rupture point); (c) Third sample (elongation and rupture point); (d) Fourth sample (elongation and rupture point)

Table 2: Stress, strain and elongation

Seed	Max. F, N	Elongation at fracture, μm	E, GPa	Strain	Stress, MPa	Elongation mm
1	84	43	1.08	0.025	0.3150	0.89
2	125	46	1.11	0.240	0.4525	0.88
3	100	35	0.94	0.253	0.4000	0.81
4	99	47	1.31	0.291	0.4100	0.87
Average	102			0.202	0.3950	0.86

It can be seen from Fig. 6a the ultimate forces requirement is 84 N to break the seed, E_f (43 N), delta elongation $(0.5-0.28) = 0.22$ mm and Stress = 1.26 MPa. From Fig. 6b, the ultimate forces requirement is about 125 N to break the seed and the force at the yield point is 45 N, delta elongation $(0.43-0.3) = 0.13$ mm and Stress = 1.81 MPa.

Table 2 presents the calculated values of the modulus and maximum stress and strain for the four seeds. The average of the values was determined as well. It can be seen that the maximum stress can be about 0.4 MPa to break the seed which can help in the future work in selecting the materials in the milling process of such seeds. Modulus found to be about 1 GPa.

Tribological Approach

It is second part of the current work, a conventional tribology machine was modified. In the modification process, there are two parts have been adopted. Firstly, it focuses to grind the seed with rubber counterface and the seeds will be as third body between the rubber wheel and the steel surface. The experiments could not be conducted properly because might be the rubber surface not hard enough and there

was no tooth on the edge disk. Although second attempt steel counterface has been used however the seeds did not fracture and there was no impact on either surface. The reason behind this issue has been found to be due to the slidings of the seeds in the interface rather than damaged by compressive and rupture process. A new approach was applied by modifying the tribo machine through putting gear below the disk acting as milling process as can be seen in Fig. 7.

After the new approach was adopted, experimental work was conducted using both counterface as can be seen in Fig. 8. The operating parameters are load: 10-20 N, Speed: 250 500 1000 rpm. In addition, optical microscopy was to examine the fracture of the seed.

Figure 8 shows the tribological result totally unexpected which, were grinding process for wheat seed with applying rubber disc and result comes out not applicable due to the seeds surfaces' tribological properties cannot affect the rubber surface and both have the same smooth external. In another word, the seed shape is not multi-angles or has not brittle shape (nature) to provide better contact with rubber disc.

Also Fig. 8 applying mild steel for grinding result find out not good enough the seed cannot grinding because the disc tribological still cannot provide best

condition to crush seed might be this issue related with the shape of wheat seed also which is ellipse shape and the steel is highly smoothed. Therefore, both disc and seed are circle shape that is making them rotate each other's rather than effect surface each other. First stage is

drawing of the gear sample: It can be seen from the Fig. 8 the gear drawing in different views as stated above (side, top and oblique) and also the dimensions are mentioned too. Second stage is drawing of the gear sample in 3D by (mechanical Software program).

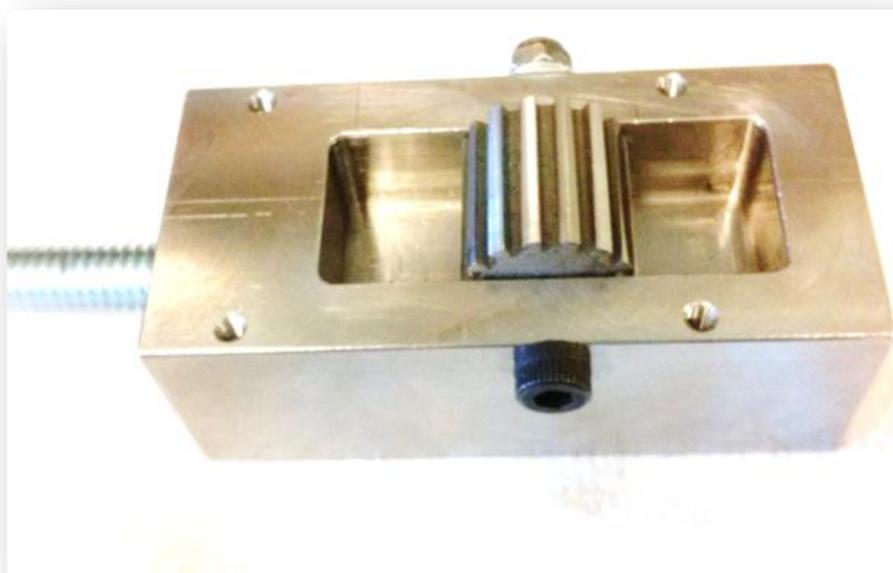
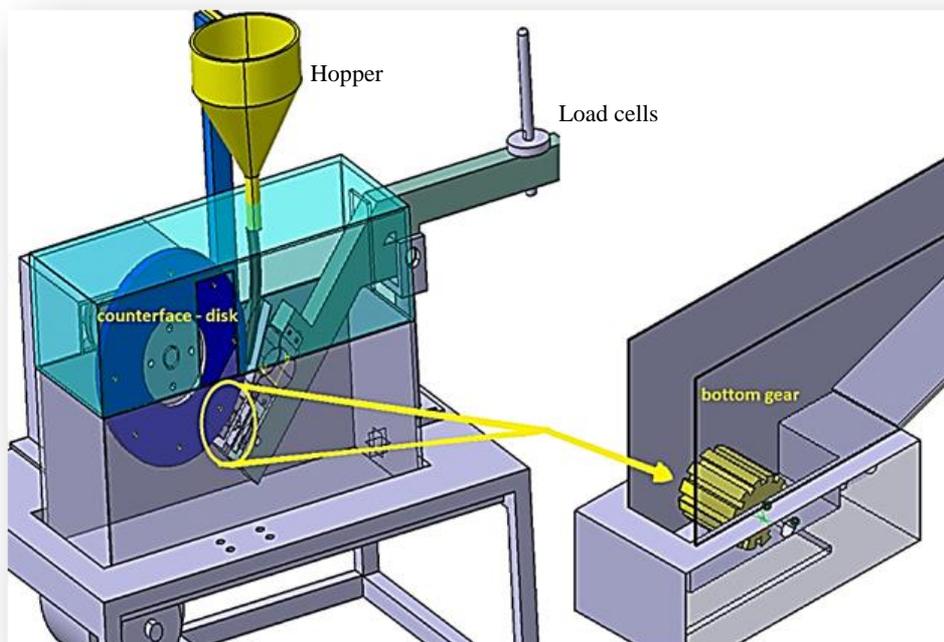
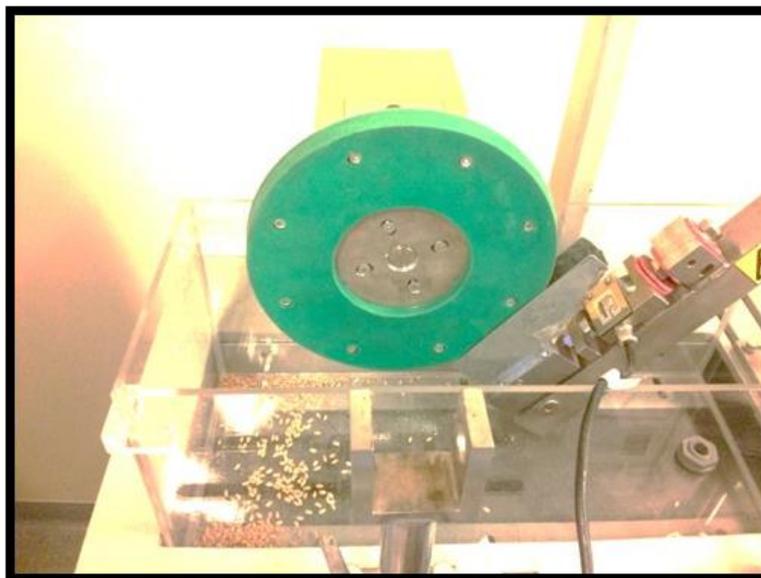


Fig. 7: Modified tribology machine with the gear, main component of the machine are, load lever, wheat hopper, load cell and modified gear



(a)



(b)

Fig. 8: Modified tribology machine; (a) With the rubber counterface; (b) With stainless steel counterface

Conclusion

From the literature review has been investigated that could polymer replace steel in the agricultural machine industry. This work is aimed at studying the effects of seed grinding process on the Tribological characteristics of components in agricultural machines. Few points can be concluded out of this study as follows:

1. From mechanical test, the *Hounsfield* compression machines test has been used for finding out mechanical result

2. From the Tribological test, the seed has been grinded by tribo-test machine running under 3BA mode with different loads, speeds and different discs
3. The modification has been done for the tribo-machine enhancing the grinding operation. The modification was putting gear under the mild steel disc
4. The smooth surface and ellipse shape are main factors that do not let discs grind seeds completely

It is acceptable that agriculture expertise and scientist think about using polymer instead of steel in agricultural machines frame and special parts however, with

considering tribological characteristics for materials that interact with each other.

Evaluating how much forces and knowing adjusting gap between discs or grinders need to breakdown and crush seed is key factor to better girding. It can be recommended for future work evaluating and comparing effect of crushing or grinding sand and wheat by polymer grinders and steel grinders.

Author's Contributions

Jasem G. Alotaibi: Results analysis and critical arguments with the literature and contribute to the introduction to draw the motivation of the work.

Ako K. Omer: Assist in the methodology and experimental done.

Nbhan D Salih: Overview writing and organization of the article.

Belal F. Yousif: Contribute to the drawing of the conclusion and identify the main contribution to the literature.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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