Determination the Mechanical Stress on the Cutter Bar of the Harvesting Combine by Abaqus

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Abstract
In this paper, to simulate mechanical stress on the cutter bar of the harvesting combine during cutting of wheat stems, first, shearing strength of the stems was measured for various moisture content levels and cutting heights. After that the cutter bar of combine was simulated by Abaqus with the specified conditions. The results of the simulation showed that with increase in moisture content of stem, shear stress on the blade is increased up to 18% due to the viscous damping effect of the moisture of stem. On the other hand, with increase in cutting height, shear stress on the blade is decreased up to 12% because of the accumulation of less mature fibers at the lower levels of stems.

Keywords
Stress, Moisture content, Cutting heights, Shearing strength, Harvesting Combine

1. Introduction

The combine harvester is a machine that harvests grain crops. The name derives from its combining three separate operations comprising harvesting-reaping, threshing, and winnowing- into a single process. Combine harvesters are one of the most economically important labor saving inventions, significantly reducing the fraction of the population that must be engaged in agriculture. The cutter bar of the various combines varied between 800 and1100 strokes per minutes.

Increasing interest in harvesting and commercial use of wheat has prompted the need for engineering data on straw properties. Most studies on the mechanical properties of plants have been done during their development using failure criteria (force, stress and energy) and the Young's modulus [1, 2]. The physical properties of the cellular material are important for cutting, compression, tension, bending, density and friction [3, 4].

Persson [5] reviewed several studies on the cutting speed and concluded that cutting power is only slightly affected by cutting speed between 1.72-5.2 m s^{-1}. Majumdar and Dutta [6] studied the required shearing energy for two varieties of rice and a variety of wheat in cutting speeds and edge angle by using a Pendulum type impact shearing device. Analysis of the data showed that the effects of crop type and edge angles on shearing energy were significant. Kushwaha et al. [7] reported mean values of shearing strength of wheat straw from 8.6 to 13 MPa with some dependence on moisture content. Other workers have measured the energy require to shear materials. O'Dogherty et al. [8] showed mean values in the range of 5.4-8.5 MPa by Measurement of the shearing strength of six varieties of wheat straw.

Chen et al. [9] conducted laboratory experiments on cutting hemp using a sickle knife section and a counter shear to determine the mechanical properties of the stems. The results showed that the cutting force and energy were significantly greater at a higher moisture content and specific mass of hemp stem.Some physical and mechanical properties of alfalfa stems were presented by Galedar et al. [10].in this research, The experiments were conducted at four moisture content levels from 10% w.b. to 80% w.b. and at three levels up the stem. At all levels along the stem, moisture contents were less than 40% w.b. did not significantly influence major and minor diameters, thickness, cross-sectional area, second moment and polar moment of area.
Tabatabaee and Borgheie [11] measured the cutting force for rice stems, therefore, was measured by designing and fabricating a static and dynamic shear test apparatus. The effects of moisture levels and the cross sectional area of stem as well as the variety, blade bevel angle, blade type and cutting speed on shearing strength have been evaluated. The results indicated that the cutting force increased with an increase in the cross-sectional area and decreased with an increase in moisture content.
In this research, biomechanical properties of wheat stem were measured to determine the mechanical stress on cutter bar of a combine. The maximum stress on the cutter bar was determined for 15%, 25%, 35% and 45% moisture contents of wheat stem and three cutting height (100, 200 and 300mm).

2. Materials and methods

2.1 Measuring the moisture content of the wheat stems

To determine the average moisture content of the wheat stems on the date of the test, the specimens gathered from the field were weighed and dried at 103°C for 24 h in the oven and then reweighed according to ASAE S358.2 DEC98 [12]. Also for reaching the target moisture contents (15%, 25%, 35% and 45%) the samples were then tested by successive weighing. Three internodes of the wheat stems, namely, lower, middle and upper internodes (100, 200 and 300mm) were studied in this research.

2.2 Measuring the shear strength of the wheat stems

In order to determine the shearing force of wheat stems, an experimental shearing apparatus with a commercial single sickle knife section and a counter shear were used as the double shear test. This simulated a single edge cutting process of a reciprocating knife of the cutter bar under a constant speed of 200 mm min^{-1}, with a Hounsfield universal testing machine (Figure 1) under a load cell 5 kN. Shearing strength of the stem was determined by dividing the shearing force into two section areas of the stem sides as Eq. (1).

$$\tau_s = \frac{F}{2A} \quad (1)$$

Where τ_s, F and A are Shearing strength, Maximum shearing force, internodes Surface Area of stem respectively.

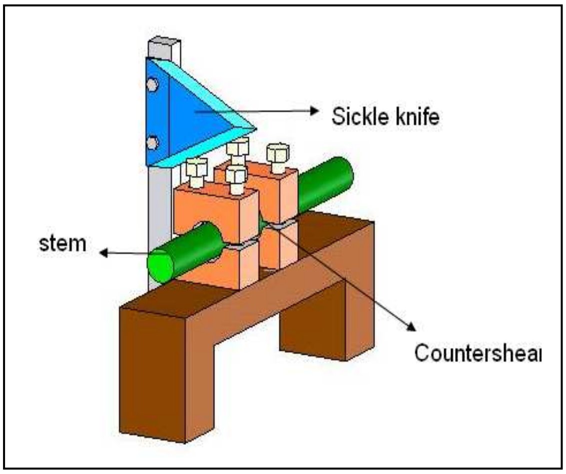

Figure 1. Schematic of shear test machine

2.3 Mechanical properties of the cutter bar material

In this research, it was considered that the blades do not rust so according to the standard [13], X38CrMoV15 (stainless steel) as material of the cutter bar was selected. Table (1) shows mechanical properties of this material. Also Poisson's ratio was considered 0.3 in this research.

Table 1. mechanical properties of X38CrMoV15

Tensile Strength, Ultimate (MPa)	Modulus of Elasticity(GPa)
900	221

2.4 Determination of mechanical stress on cutter bar

In this research, the cutter bar was modeled in Abaqus software. To simulate the cutter bar first, 3D drawing of the cutter bar was input to the software. After that the mechanical properties of the material of the cutter bar was specified in the software. According to movement of the cutter bar Dynamic, Implicit mode was considered. Surface traction was also selected as the type load the cutter bar and 3 ms^{-1} was considered as the movement speed of the cutter bar [14].

3. Results and Discussion

3.1 Mechanical parameters of wheat stem

According to the results, mean values of shearing strength of wheat stem for 15%, 25%, 35% and 45% moisture contents were shown in Table 2:

Table 2. Shear strength of wheat stem for various moisture contents

Shear strength (MPa)	Moisture content (%)
3.25	15
3.57	25
3.69	35
3.86	45

According to the results, mean values of shear strength of wheat stem for three cutting height (100, 200 and 300 mm) were shown in Table 3:

Table3. Shear strength of wheat stem for various cutting height

Shear strength (MPa)	Cutting height(mm)
3.80	100
3.62	200
3.35	300

3.2 Mechanical stress on cutter bar for various moisture contents

Figures 2-5 show Mechanical stress on cutter bar for various moisture contents of stem.

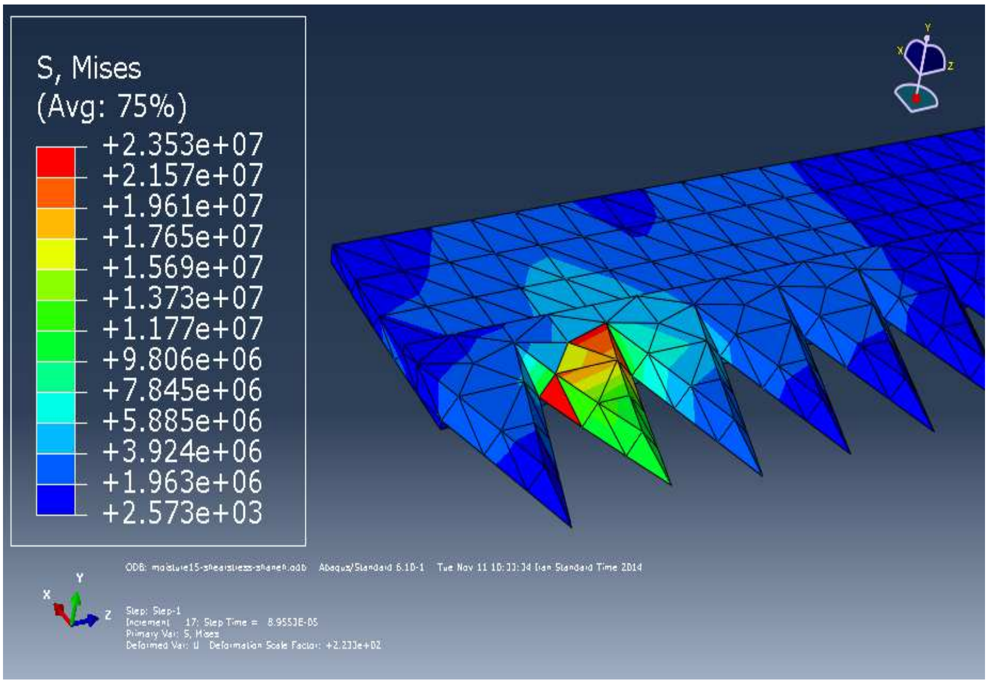

Figure2. Stress contour of cutter bar for 15% moisture content condition

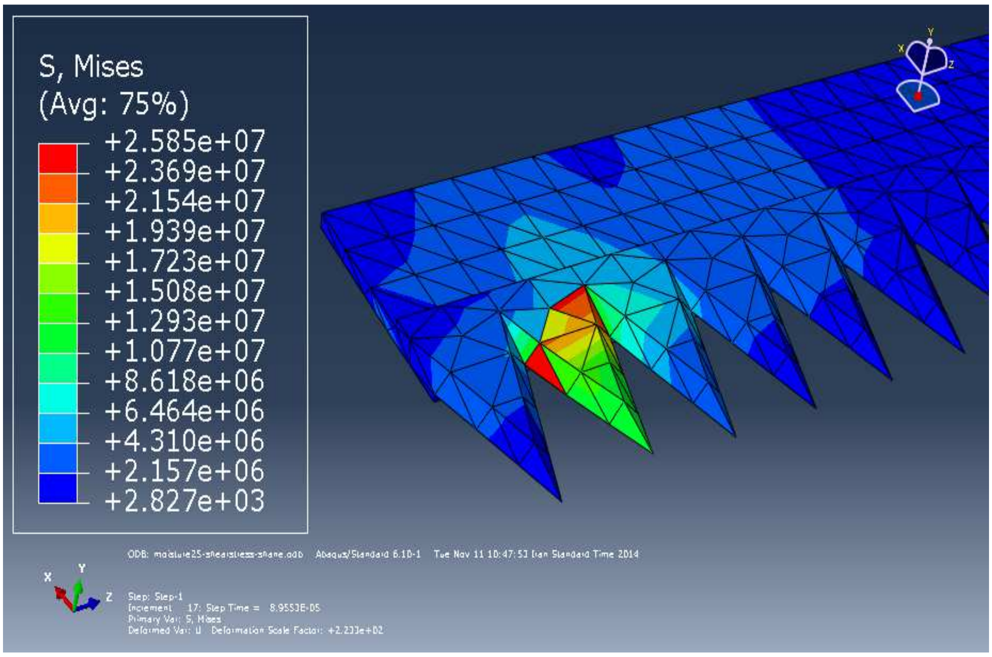

Figure3. Stress contour of cutter bar for 25% moisture content condition

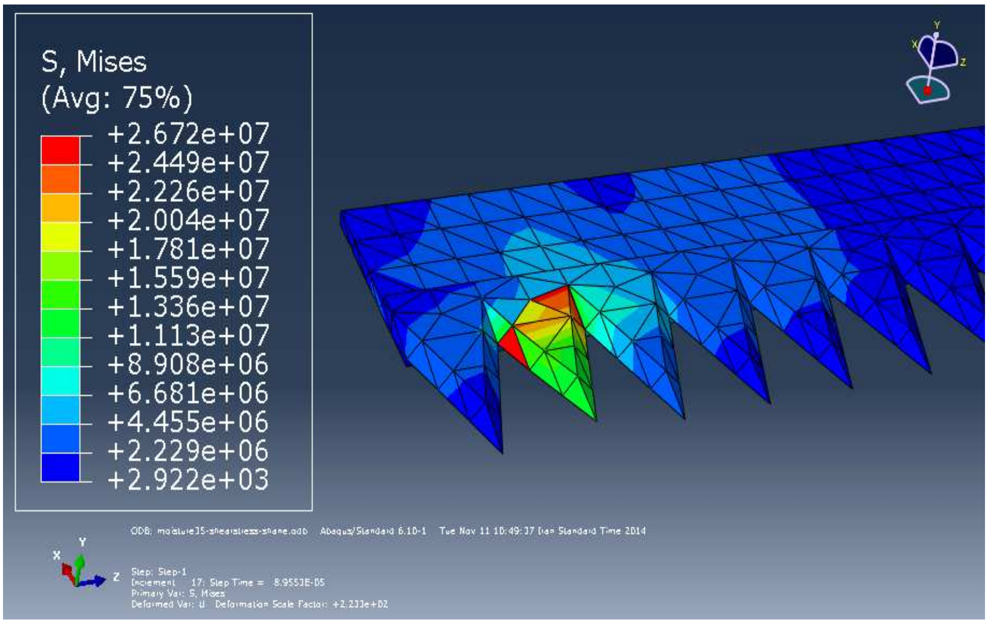

Figure4. Stress contour of cutter bar for 35% moisture content condition

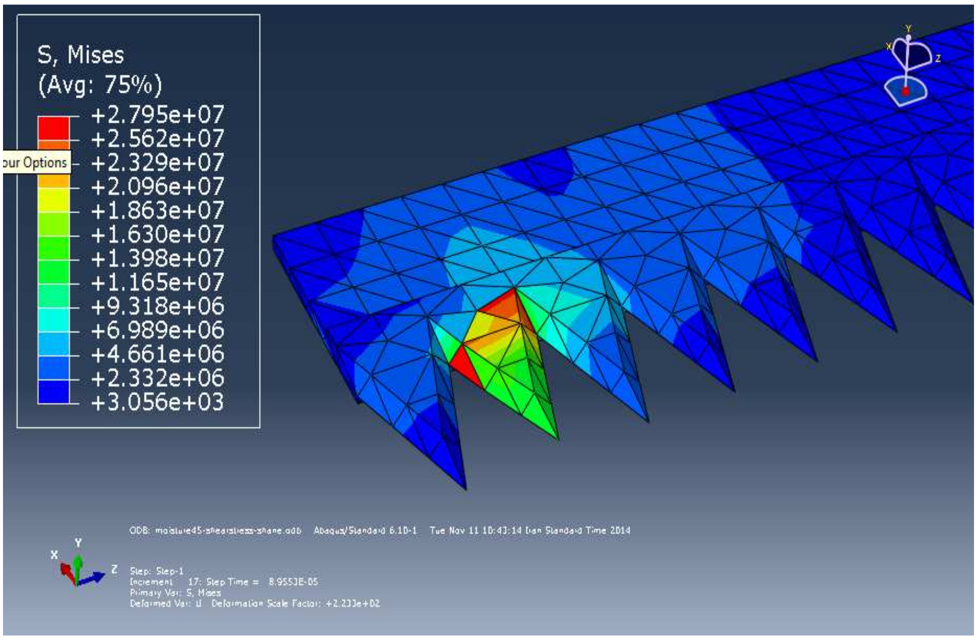

Figure5. Stress contour of cutter bar for 45% moisture content condition

According to the Figures 2-5 the maximum stress on cutter bar is 23.53, 25.85, 26.72 and 27.95 MPa and the minimum stress on cutter bar is 2.57, 2.82, 2.92 and 3.05 MPa for 15%, 25%, 35% and 45% moisture contents respectively.

Figures 6 and 7 show the mean values of the maximum and minimum stress on cutter bar for 15%, 25%, 35% and 45% moisture contents.

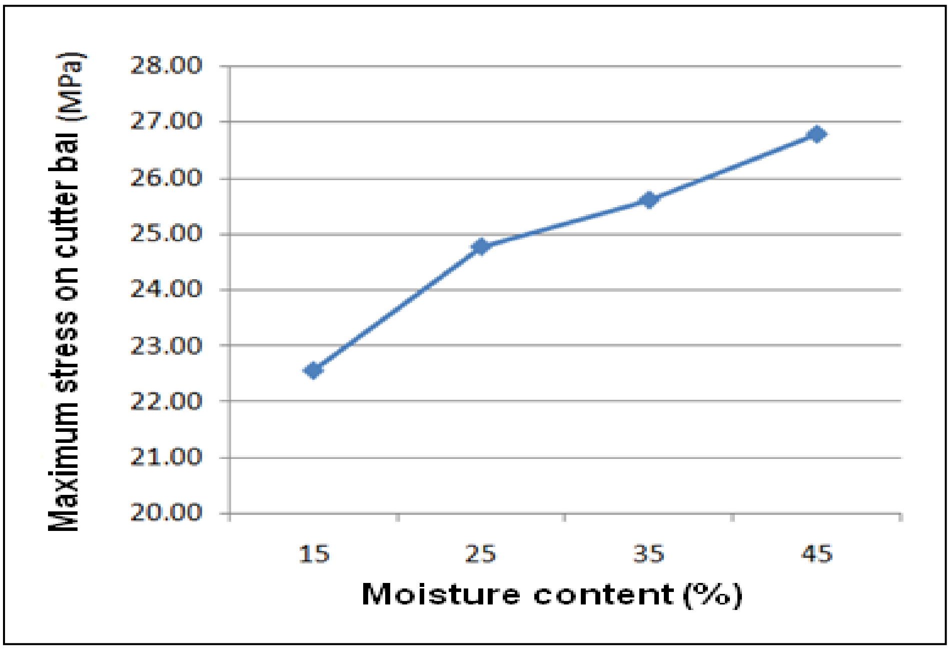

Figure6. Mean values of the maximum stress on cutter bar for 15%, 25%, 35% and 45% moisture contents

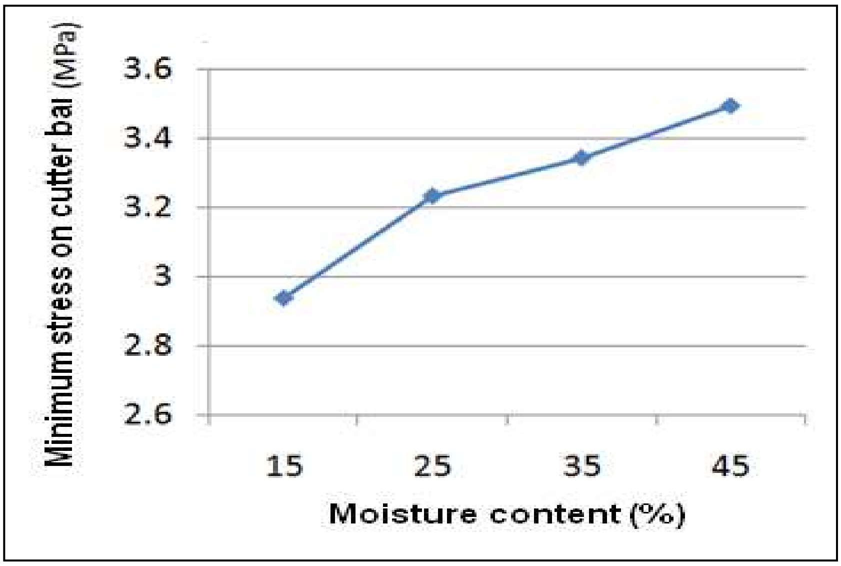

Figure7. Mean values of the minimum stress on cutter bar for 15%, 25%, 35% and 45% moisture contents

The results are obtained with an increase in moisture content, the shear strength increases by 18.8%. Also with an approximately 30% increase in moisture content, mean value of the maximum stress on cutter bar increases from 22.55 to 26.79 MPa. But the position of cutter bar that the maximum stress happens on is same. The possible reason for increasing the stress on cutter bar is the viscous damping effect of moisture and secreted substances in the stems which cause higher shear strength [9].

3.2 Mechanical stress on cutter bar for various cutting heights of stem

Figure 8-10 show Mechanical stress on cutter bar for various cutting heights of stem.

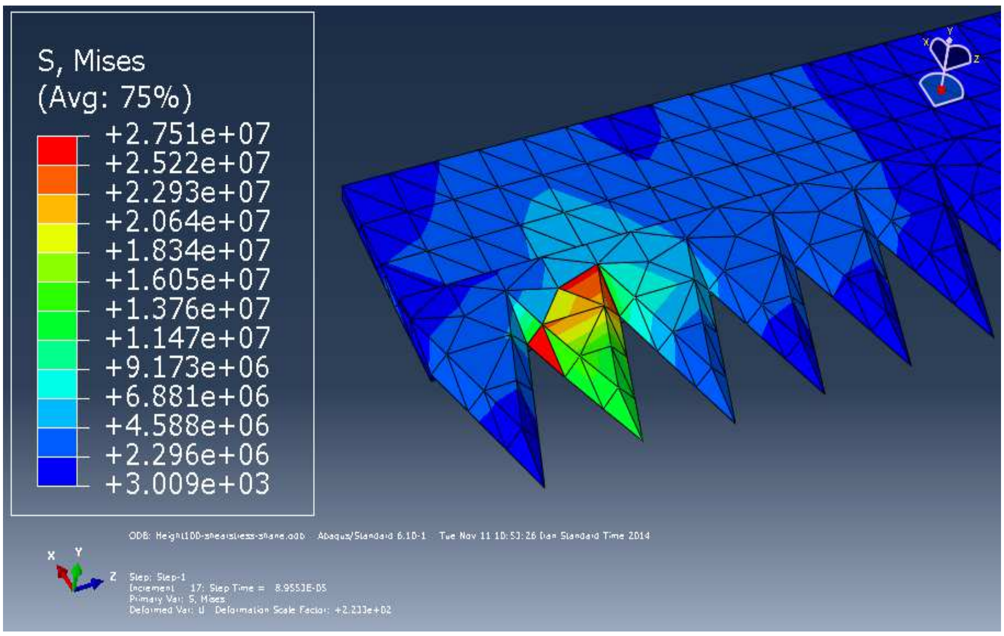

Figure8. Stress contour of cutter bar for 100 mm cutting heights

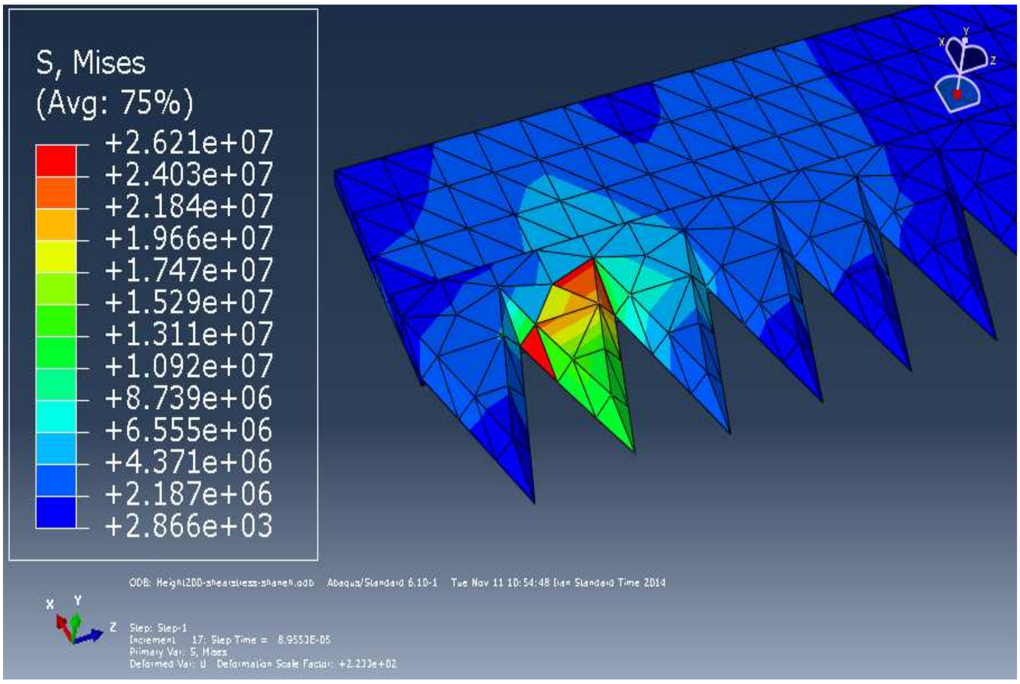

Figure9. Stress contour of cutter bar for 200 mm cutting heights

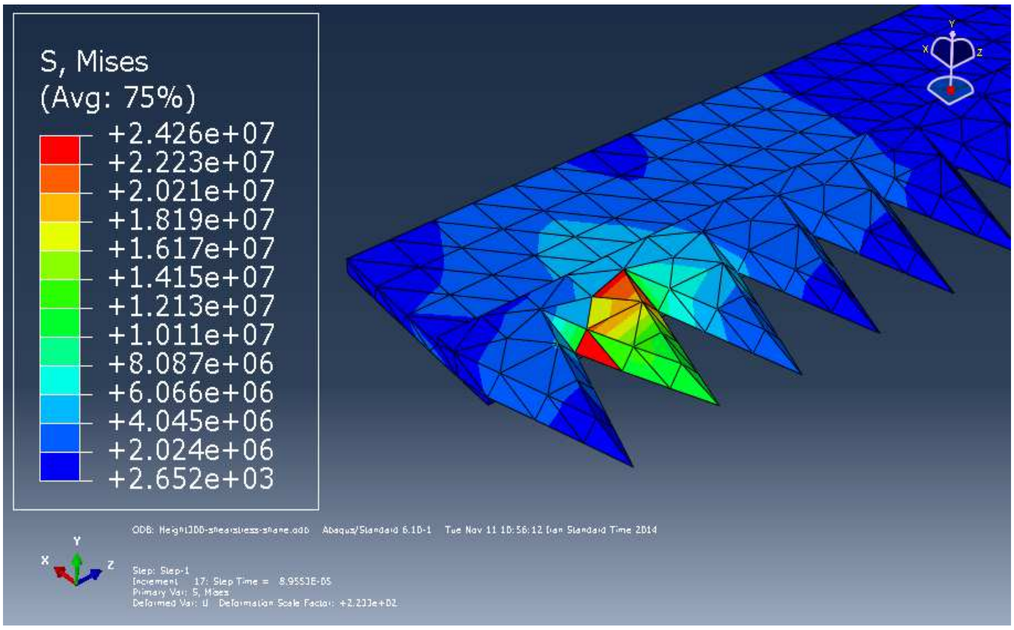

Figure10. Stress contour of cutter bar for 300 mm cutting heights

According to the Figures 8-10 the maximum stress on cutter bar is 27.51, 26.21 and 24.26 MPa and the minimum stress on cutter bar is 3, 2.86 and 2.65 MPa for 100, 200 and 300mm cutting height respectively.

Figures 11 and 12 show the mean values of the maximum and minimum stress on cutter bar for 100, 200 and 300 cutting height.

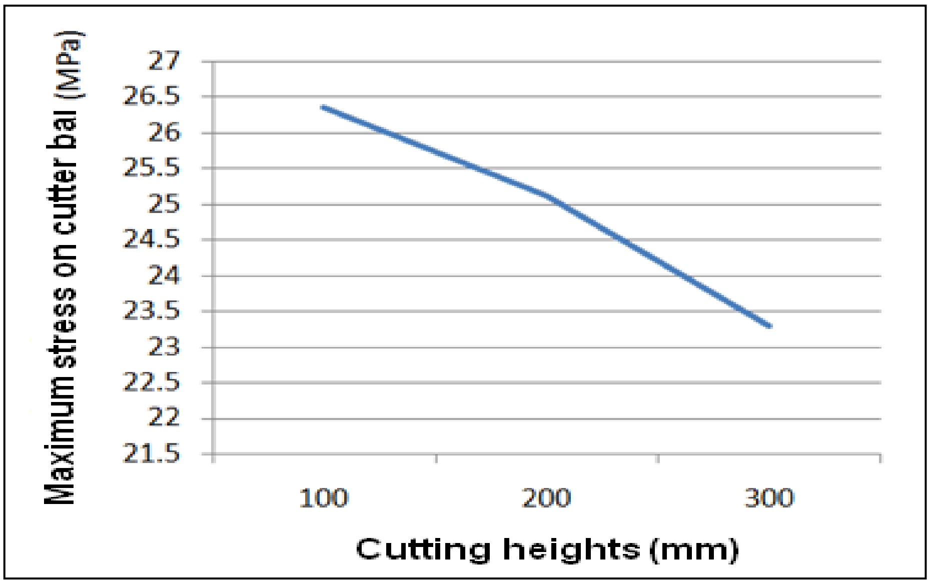

Figure11. Mean values of the maximum stress on cutter bar for 100, 200 and 300 mm cutting height

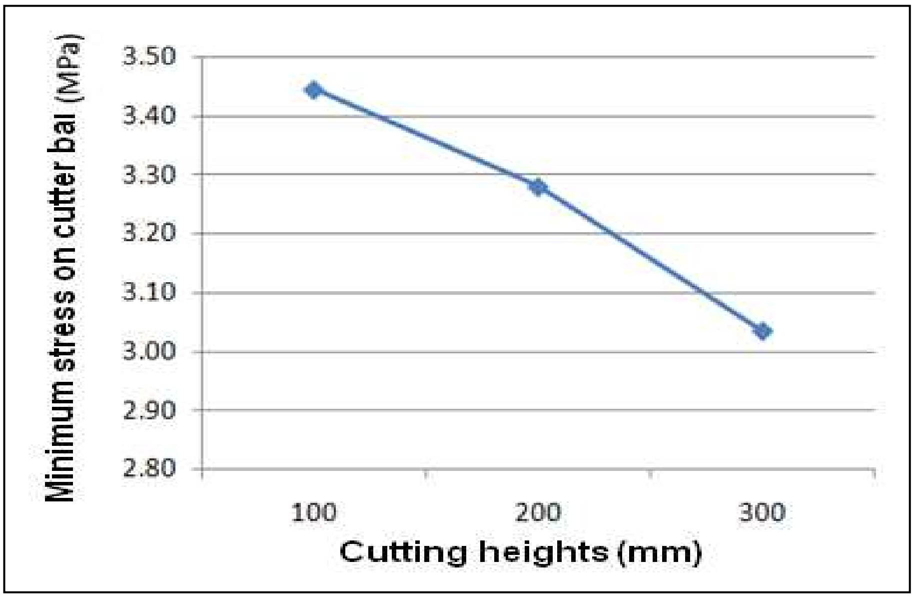

Figure12. Mean values of the minimum stress on cutter bar for 100, 200 and 300 mm cutting height

According to the results, the stress on cutter bar decreases up to 12% while cutting height increases. It could be due to the accumulation of lesser mature fibres in the stem that causes lower shear strength [15].

4. Conclusions

- The results are obtained with an increase in moisture content, the shear strength increases by 18.8%.
- With an approximately 30% increase in moisture content, mean value of the maximum stress on cutter bar increases from 22.55 to 26.79 MPa.
- The stress on cutter bar decreases up to 12% while cutting height increases due to the accumulation of lesser mature fibres in the stem.

5. References

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