Tikrit Journal for Agricultural Sciences
ISSN:1813-1646 (Print); 2664-0597 (Online)
Journal Homepage: http://www.tjas.org
E-mail: tjas@tu.edu.iq

TJAS
Tikrit Journal for Agricultural Sciences

DOI: https://doi.org/10.25130/tjas.25.3.18

Simulation of stress and bending moment occurring on conventional and slatted moldboard's plough using finite element method and validate by experiment

Mahmood A. Hussein[1,*] Adnan A. A. Luhaib[1] Adel A. A. Rajab[2] and Marwan D. Ghanam[3]

[1] Department of Agricultural Mechanization Technologies, Center for Arid Farming and Conservation Agriculture Research's, University of Mosul, Mosul, Iraq.
[2] Dep. of Agricultural machines and equipment, College of Agriculture and Forestry, University of Mosul, Mosul, Iraq.
[3] Salah Al-Din Agriculture directorate, Salah Al-Din, Tikrit, Iraq.
Correspondence email: mahmood.hussein@uomosul.edu.iq

KEY WORDS:
Conventional moldboard, principle stress, bending moment, FEM, ANSYS

Received:	29/06/2025
Revision:	05/08/2025
Proofreading:	18/08/2025
Accepted:	05/09/2025

Available online: 30/09/2025

ABSTRACT
Moldboard is one of the most important working parts of a plough; it is the most vulnerable to stress due to working through the soil. Thus, the study aimed to determine the extent of the moldboard's ability to withstand stress and bending torque. The stresses affecting the structure of the moldboards were examined and analyzed under conditions similar to the field conditions in which the flip-flop moldboard plough operates, using the Finite Element Method (FEM) with the ANSYS software. The principal stresses, principal strains, and displacement ratio were adopted in the first stage. In the second stage of the study, the results were tested in the field to investigate the performance of two shapes of moldboards (standard - conventional and slatted moldboard) at two soil moisture contents (SMC) (10.23% and 16%) utilizing two forward speeds (4.96 and 6.20 $km.h^{-1}$) to determine the impact of these factors on stress and bending moment. Theoretically, the slatted moldboard outperformed the conventional moldboard by 7% and 13% recording lower principal stress and lower principal strain, respectively. However, the conventional moldboard's continuous surface offered greater structural stability, showing 45% less displacement. Practically, the results indicated that the stress increased when SMC decreased, and respond positively with speed. Meanwhile, the manufactured slatted moldboard recorded the lowest bending moment under all tested factors.

محاكاة الاجهاد وعزم الانحناء الحاصل على المطرحتين التقليدية والمشرحة للمحراث المطرحي باستخدام طريقة العناصر المحددة نظريا واختبارها عملياً

محمود عواد حسين[1]، * ، عدنان عبد احمد لهيب[1] ، عادل احمد عبدالله رجب[2]، مروان ذياب غانم الغنام[3]

[1] قسم التقنيات الميكنية، مركز بحوث الزراعة الجافة والحافظة، جامعة الموصل ، العراق
[2] قسم المكائن والالات الزراعية، كلية الزراعة والغابات، جامعة الموصل، العراق
[3] مديرية زراعة صلاح الدين، وزارة الزراعة، العراق

الخلاصة

تعتبر المطرحة واحدة من اهم الاجزاء العاملة والشغالة في المحراث المطرحي القلاب، والاكثر عرضه للاجهادات نتيجة عملها في رفع التربة وتفكيكها وقلبها. لذا هدفت الدراسة لتحديد قدرة المطرحة على تحمل الاجهادات وعزم الانحناء. فحصت وحللت الاجهادات المؤثر في هيكل المطارح وفي ظروف مشابهة للظروف الحقلية التي يعمل فيها المحراث المطرحي بطريقة العناصر المحددة باستخدام برنامج ANSYS. في المرحلة الاولى اعتمدت الاجهادات الرئيسية والانفعالات الرئيسية ونسبة الانحراف، اما في المرحلة الثانية للدراسة، اختبرت النتائج حقليا للتحقق من اداء شكلين من المطارح (التقليدية، والمشرحة المصنعة محليا) عند مستويين من المحتوى الرطوبي (10,23%) و (16%)، وباعتماد مستويين من السرعة الامامية للحرث 4,96 و 6,20 كم.سا$^{-1}$ لتبيان مدى تأثير هذه العوامل في الاجهاد وعزم الانحناء. نظريا: تفوقت المطرحة المشرحة بنسبة 7% و13% بتسجيلها اقل اجهاد رئيسي واقل انفعال رئيسي مقارنة مع المطرحة التقليدية، وعلى التوالي. في حين حققت المطرحة التقلديدية 45% اقل عزم انحناء مقارنةً مع المطرحة المشرحة. حقليا (عمليا): بينت النتائج انه كلما زاد المحتوى الرطوبي للتربة، تنخفض قيم الاجهادات، بينما زادت القيم مع زيادة السرعة الامامية للحرث. وفي ذات الوقت سجلت المطرحة المشرحة اقل عزم انحناء عند جميع العوامل المدروسة.

الكلمات المفتاحية: المطرحة التقليدية، اجهاد رئيسي، عزم الانحناء، طريقة العناصر المحددة.

INTROUCTION

There are many types of ploughs used on Iraqi farms, and the moldboard plough is among the most common and widely used. These ploughs, especially the working parts that interact with the soil, are usually made from different metals, as each soil texture requires a specific type of metal. in clayey soils, the working parts of ploughs are made from high-carbon steel due to the high resistance and stress of the soil, while in sandy soils, the plough working parts are made from cast iron because of the high friction and rapid wear (Al-Janobi, 2000; Srivastava *et al.,.*, 2006; Natsis *et al.,.*, 2008; Saleh *et al.,.* 2020).

The moldboard of the moldboard plough is responsible for turning over the soil section, mixing, and burying plant residues to decompose later and increase soil fertility (Spoor and Godwin, 1978; McKyes, 1985; ASAE, 1993, ASABE, 2016; Mwiti *et al.*, 2023). These moldboards vary in shape and consume a considerable amount of energy, making it essential to design and adjust them to match the suitable soil moisture content and forward speed for the ploughed soil texture to achieve ploughing with minimal energy (Abo-Elnor *et al.,.*, 2004; Godwin, 2007; Upadhyaya *et al.*, 2009).

When designing the moldboard plough, there is a clear focus on stress distribution across its parts to determine their resistance to external forces. Therefore, it is necessary to understand the stresses they can endure when working under unfavorable conditions or during irregular and unbalanced operations (Ergech and Tahir, 2008). Stress increases with reducing moisture content or increasing forward speed. This might be attributed this to the heightened cohesion between soil particles and the increased pressure from the action, which results in greater momentum (Dula and

Anawute, 2021).

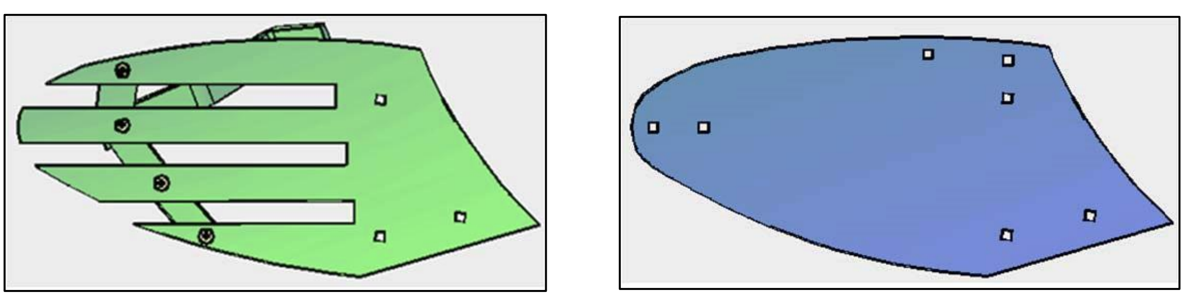
Stress was analyzed by Abdullah (2017) in two approaches; theoretically via the ANSYS program based on the Finite Element Method (FEM) and empirically through field evaluation to ascertain stress distribution on the plough under conditions as close as possible to real ones. When comparing the values, the practical results were greater than the theoretical values due to certain field obstructions that increased the stress values. According to Selvi (2017), an increased bending angle of the blade inside the soil raised cutting resistance and, consequently, stress. Additionally, the type of alloy used in manufacturing the blade impacts the stress value.

As the moldboards consume a significant amount of the total energy spent during ploughing and with few local studies available on them, it is necessary to conduct a study on the locally manufactured slatted moldboard to determine its capability and endurance under withstand stress and bending torque compared with the standard-conventional moldboard.

MATERIAL AND METHODS

The experiment was carried out in agricultural field in Rahmaniyah area, Northeast of Mosul city. Soil texture analysis showed a loamy-silty texture with 28% sand, 52% silt, and 20% clay. A Massey Ferguson MF275 tractor was used in this experiment. The research was conducted by using the three-body standard moldboard plough of Turkish origin with a width of 82 cm and weight of 290 kg. But the moldboards were not full length; they were trimmed squad landsides. Slatted moldboards were manufactured by Northern Mechanical Industries, a company located in Mosul city. A uniform tillage depth of 20-30 cm was maintained for both conventional and manufactured plows throughout the trial. The alloy's metal composition percentages and type were determined (Higgins, 1993).

The chemical composition and mechanical properties of these moldboards are given in the following table known as Table 1. The physical structure of the conventional moldboard and the locally manufactured slatted moldboards used in this study and their designs blueprint are shown in Figure 1. At this stage, the basic dimensions and measurements of the moldboards were also taken and as illustrated in the Figures. According to these dimensions and measurements, the type of metal used and its mechanical properties of the moldboards were designed and developed with the help of Finite Element Method (FEM) using ANSYS program. This method determined the distribution of stresses affecting the structure of the moldboards and their endurance to those stresses, based on the results obtained using the applied loads and forces.



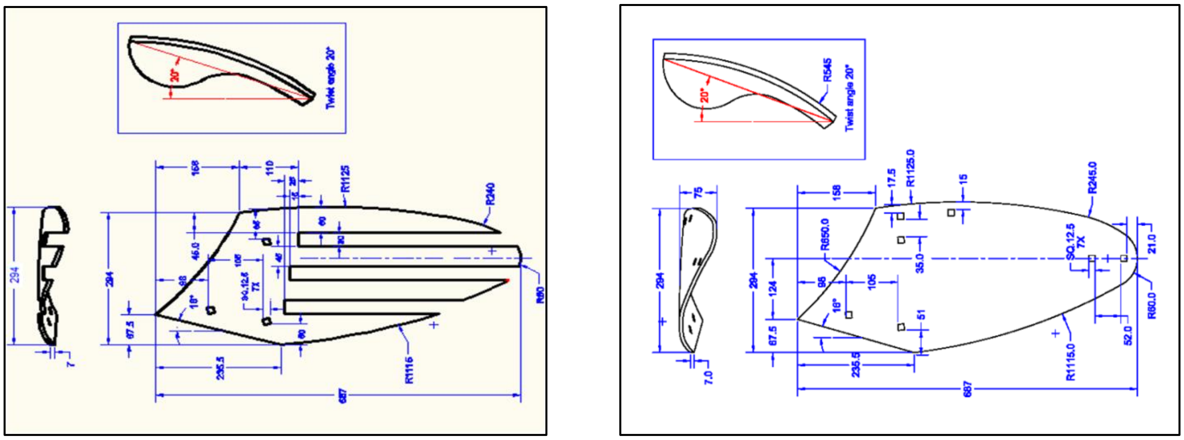


Fig. 1. Illustrated slatted and standard-conventional moldboards (top-left and top-right), respectively; and design blueprint of slatted (bottom-left) and conventional (bottom-right) moldboards.

Three main factors were investigated at this study, which were as follow:

1. Two shapes of moldboard ploughs (conventional and locally manufactured slatted moldboards).
2. Two levels of moisture content (10.23% and 16%).
3. Two levels of forward ploughing speed (4.96 and 6.20 km.h^{-1}).

Table 1. Shows the chemical composition and mechanical properties of the moldboards of the moldboard plough used in the experiment.

	Metal Type	**Percentage**	**Alloy Symbol**
	Iron%	94.45	
	Carbon%	0.612	
Chemical composition	Silicon%	0.329	
	Manganese%	1.34	
	Chromium%	0.199	
	Molybdenum%	0.204	
	Tungsten%	2.45	**Low steel**
	Tensile Strength (N mm^{-2})	2847.5	
Mechanical properties	Hardness (HRC)	42.84	
	Yield Strength (N/mm2)	2741.5	
	Elongation Ratio (%)	13.97	

The direct stress was measured in the field using strain gauges. These sensors were connected to an electronic circuit (Microcontroller - Arduino Uno R3), as shown in Figure 2 (left), which was assembled by connecting the electronic components together, then installing, programming, and integrating them with a portable computer to measure the strain experienced by the moldboard and its shank at the point where the strain gauge was fixed (Figure 2 right). The strain gauge was positioned on the rear surface of the moldboard in the lower third of its height and in the first quarter of its length, at the center of resistance (X and Y coordinates).

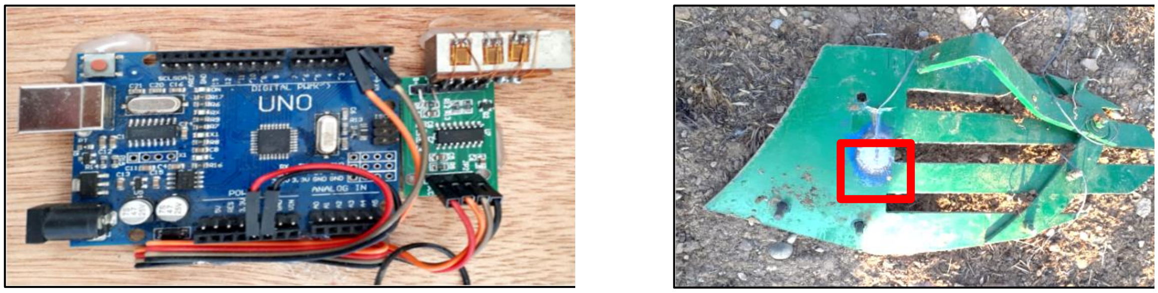


Fig. 2. Electronic circuit (left) and fixed stain gauge on slatted moldboard (right)

To ensure the sensors were working correctly before connecting them to the electronic circuit, they were tested with a voltmeter used to measure voltage. These moldboards and their shank experience direct stresses during operation. The strain gauge, which is the main component used with the strain measurement device, measures the strain and changes occurring in the metal moldboards directly during operation. The specifications of the strain gauge are as follows: Type: KFC-5-C1-11z800, Length: 5 mm, Thermal Tolerance: ±1.8 Micro Strain/°C, Gauge Factor: 2.15% ± 1, Electrical Resistance: 120 ± 0.3.

Regarding the electronic circuit, several organizational and operational procedures were carried out before measurement. These procedures, specific to the electronic circuit with the sensor, helped determine the strain value, which in turn contributed to finding the stress value and indicating its impact during operation. Based on this, all equations below as per the method described by Hearn (1985).

$$\sigma = \frac{P}{A} \qquad (1)$$

Where:
σ: Stress ($N.m^{-2}$)
P: Force (N)
A: Area (M^2)

When stress is applied to body, the resulting change in its length defines strain, as calculated in the following equation:

$$\varepsilon = \frac{\delta L}{L} \qquad (2)$$

Where:
ε: Strain
δL: Change in length
L: Original length

Strain also quantifies material deformation. It may expressed as a percentage.

$$\varepsilon = \left(\frac{\delta L}{L}\right) \times 100 \qquad (3)$$

As for the bending moment, the simple theory of flexural bending states that:

$$\mathrm{M} = F.d \qquad (4)$$

Where:
M: The moment (Nm),
F: Force (N),
d: Vertical dimension (m)

$$\frac{M}{I} = \frac{\sigma}{Y} = \frac{E}{R} \qquad (5)$$

Where:
I: Area Moment of inertia (m^2)
Y: Distance from the neutral axis to the moldboard section for applied stress (m)
E: Modulus of elasticity
R: Radius of curvature of the neutral axis of the section (m)
From the above equation, stress and bending moment for any part of the working sections can be obtained (Hearn, 1985).

RESULTS AND DISSCUSION

The stress, principal strain, and displacement (deviation ratio) for the conventional and locally manufactured slatted moldboards of the moldboard plough were determined using the ANSYS program, which relies on the Finite Element Method (FEM). This was done to understand how the moldboards withstand the stress applied to them and how it is distributed on the working surfaces under conditions similar to field conditions.

Figure 3, top and bottom illustrated the principal stress for the two moldboards, slatted and conventional. The slatted moldboard outperformed by recording lower principal stress (0.17 MPa) compared to the conventional moldboard, which recorded higher principal stress (0.18 MPa). Figures 4, top and bottom depict the principal strain obtained for the two moldboards. The slatted moldboard recorded lower values (6.85 MPa) compared to the conventional moldboard, which recorded higher values (7.879 MPa). This difference can be attributed to the design variation between the two moldboards. The sections that were cut and removed from the slatted moldboard reduced the contact area between the soil section and the working surfaces, allowing some of the cut soil to pass through, thereby reducing the force required for cutting, turning, and disintegration, ultimately reducing the principal strain equally. These findings align with established principles of soil-tool interaction, confirming that reduced contact area and controlled soil flow through geometric modifications effectively lower implement stresses and draught forces (Godwin *et al.*,., 2007; Ahmadi., 2016).

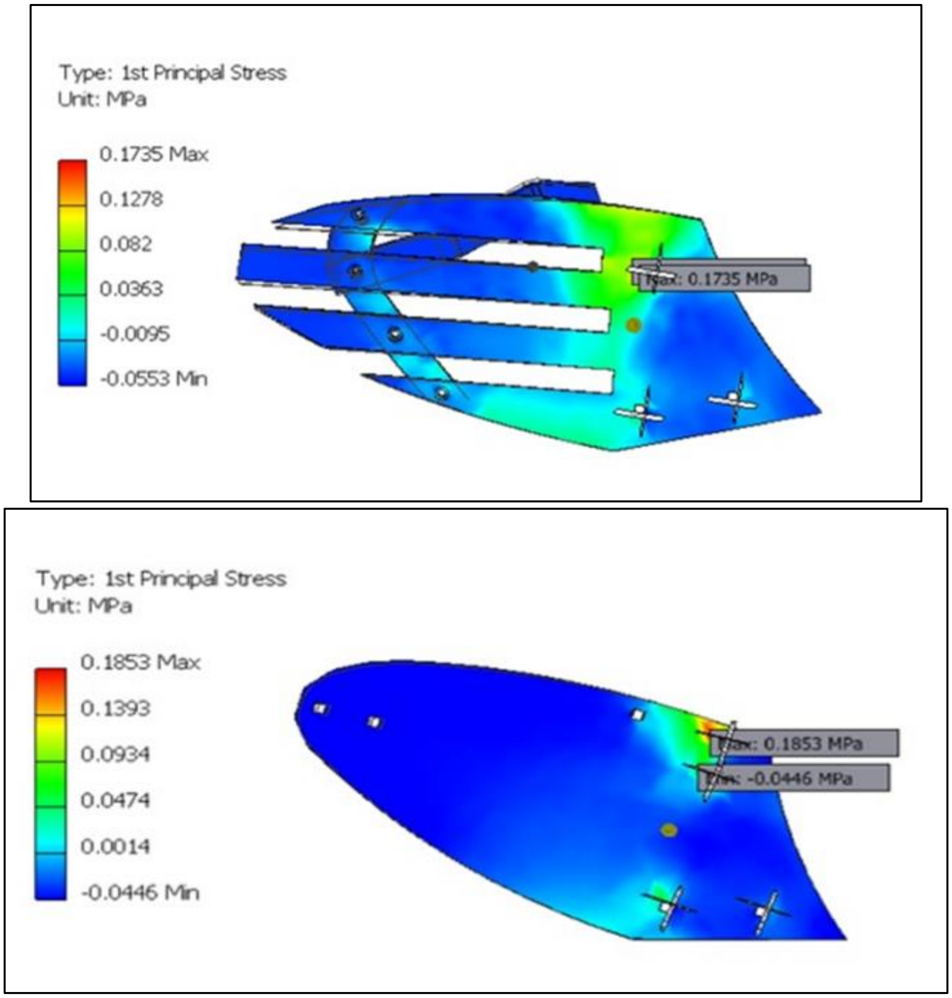
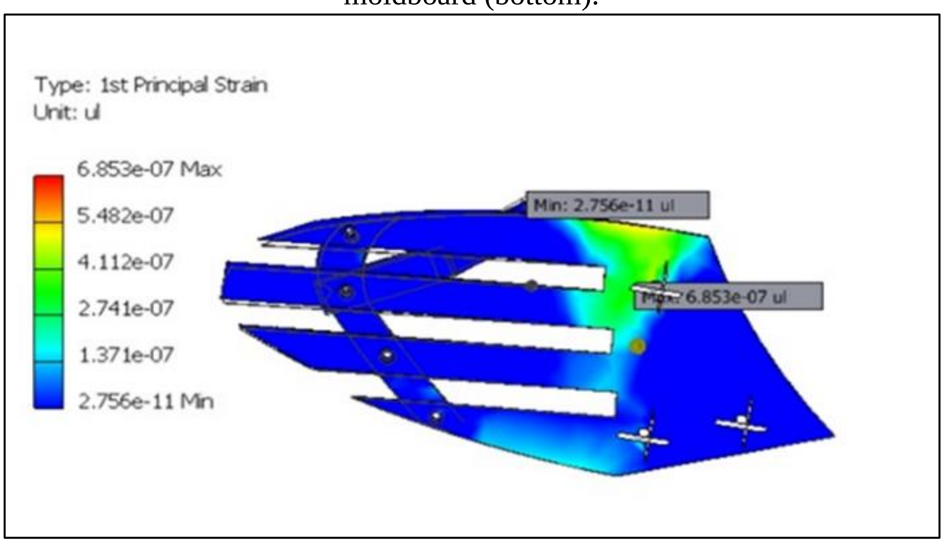


Fig. 3. Distribution of principal stresses on the slatted moldboard (top); and conventional moldboard (bottom).



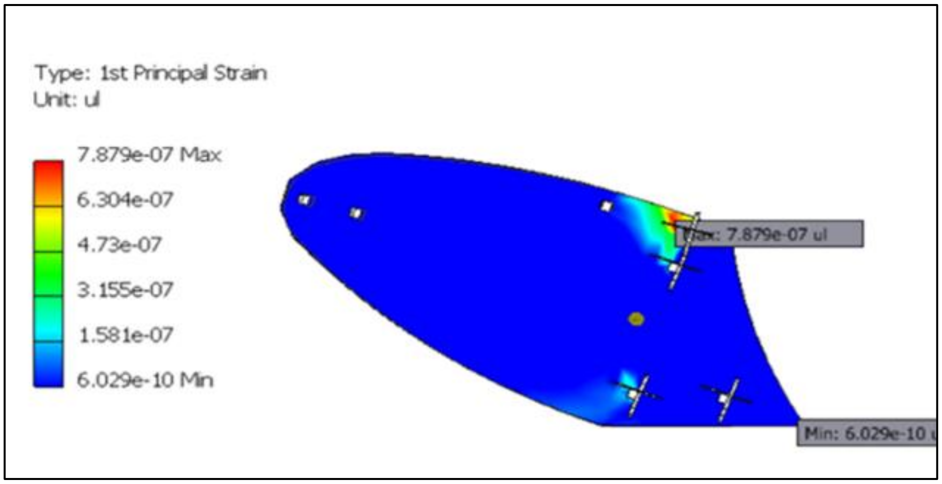
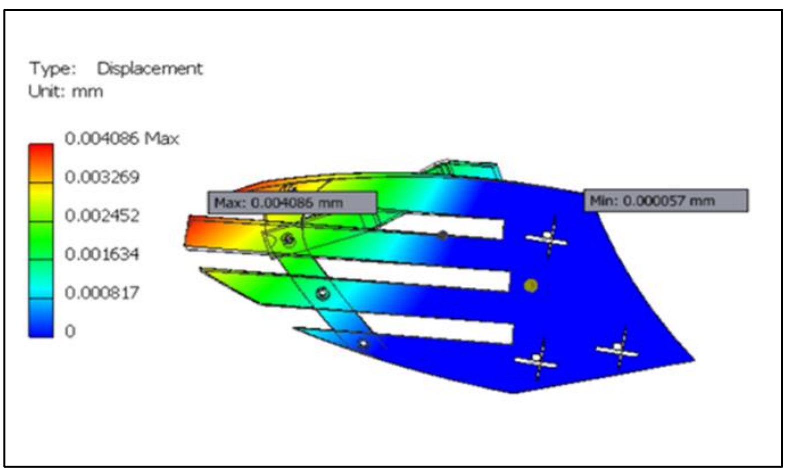


Fig. 4. Distribution of principal strains on the slatted moldboard (top); and conventional moldboard (bottom).

The conventional moldboard outperformed by recording lower displacement (0.0022 mm) compared to the slatted moldboard, which recorded higher displacement (0.0040 mm), meaning a lower deviation ratio. This can be attributed to the fact that the conventional moldboard has a hard and smooth surface, which provides more strength and stability during cutting, turning, and disintegration compared to the slatted moldboard, whose surface is less stable during operation (Figure 5, top and bottom).



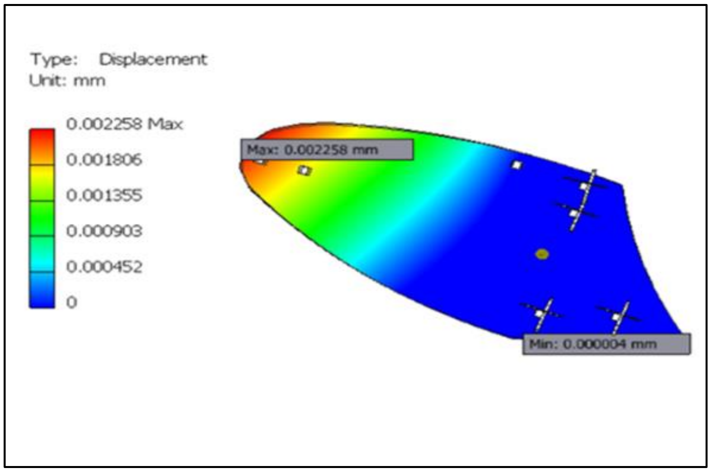


Fig. 5. Distribution of displacements (displacement ratio) on the slatted moldboard (top); and conventional moldboard (bottom).

The stress values on both the conventional and slatted moldboards decrease as soil moisture content increases. Additionally, it is observed that as the ploughing speed increases, the actual stress values on both moldboards tested in the experiment increase. The results indicated that the lowest stress value was recorded at a moisture content of 16% when the slatted moldboard was used at a ploughing speed of 4.96 km.h^{-1}, which was 0.182 MPa. In comparison, the lowest stress using the conventional moldboard was 0.198 MPa at the same speed and moisture content (4.96 km.h^{-1} and 16%, respectively). At the speed of 6.20 km.h^{-1} and the same moisture content of 16%, the slatted moldboard again recorded a lower field stress value compared to the conventional moldboard (0.191 vs. 0.203 MPa, respectively), as showed in Figure 6.

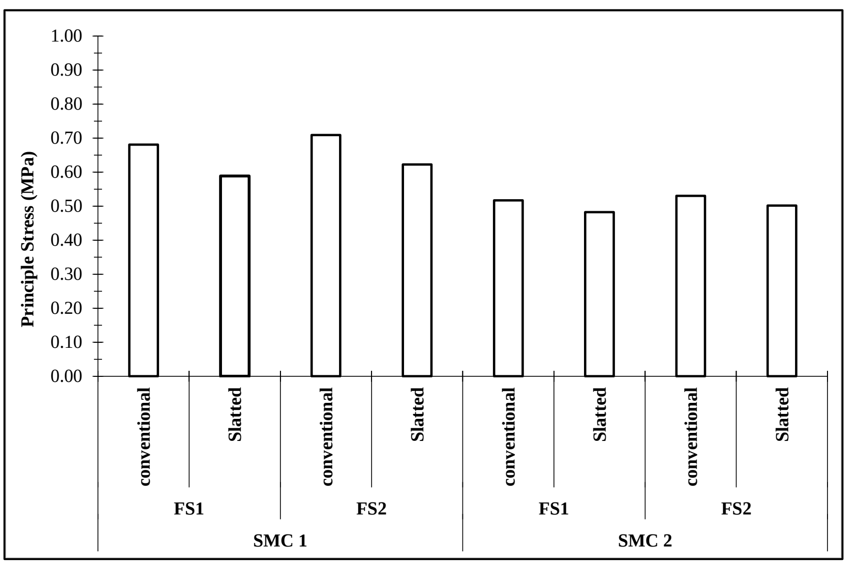


Fig. 6. Total Stress occurred on slatted and conventional moldboards as affected by Soil Moisture Content (SMC) and Forward Speed (FS).

The highest stress values were recorded at a moisture content of 10.23% for both moldboards and both forward speeds. The conventional moldboard recorded 0.215 and 0.225 MPa at speeds of 4.96 and 6.20 km.h^{-1}, respectively, while the highest stress values for the slatted moldboard were 0.205 and 0.208 MPa at the respective speeds. The fluctuation in stress values is directly related to speed and moisture content; as forward speed increases and relative humidity decreases, soil resistance to penetration increases along with the pressure exerted by the moldboards on the soil slice. This effect was more pronounced with the conventional moldboard compared to the slatted moldboard. The design of the slatted moldboard, with gaps between the slatted s, allows part of the soil slice to pass through, thereby reducing the stress values compared to the conventional moldboard. The differences between theoretical and practical principle stress were recorded at less than 20% in most cases, which aligns with the data obtained by (Al-Irhayim *et al.*,., 2025; Ergech, and Tahir, 2008; Zeytinoglu, 2002), who confirmed that the differences and the data derived from ANSYS software were acceptable under these field conditions.

The bending moment increased with the decrease in soil moisture content and the increase in forward ploughing speed for both moldboards. However, the slatted moldboard recorded lower bending moment values under all studied factors. The slatted moldboard achieved the lowest bending moment value (139.5 Nm) at a speed of 4.96 km.h^{-1} and a moisture content of 16%, while the best bending moment value for the conventional moldboard was 141.90 Nm at the same forward speed and moisture content. The bending moment values for both moldboards (slatted and conventional) increased as the speed was raised to 6.20 km.h^{-1} with the same moisture content, recording 143.15 and 146.18 Nm, respectively (Figure 7).

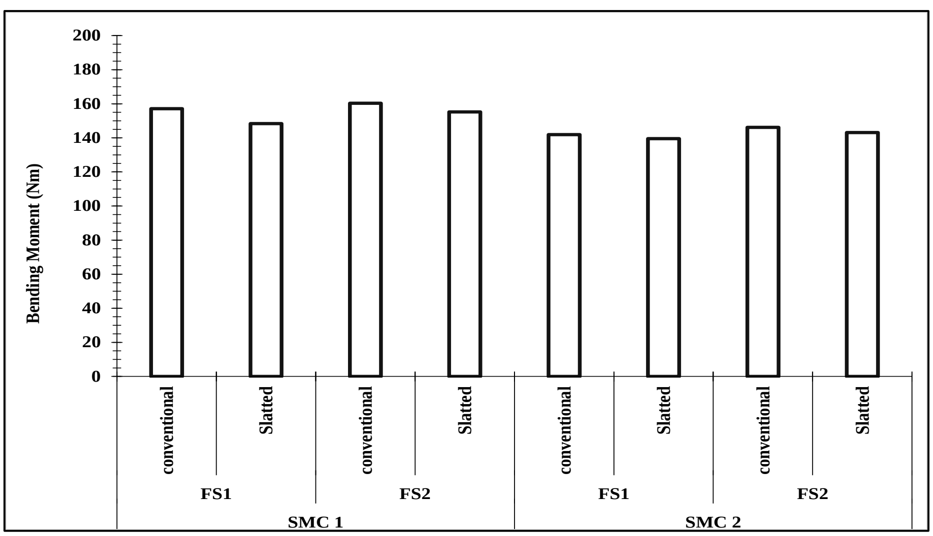


Fig. 7. Bending moment occurred on slatted and conventional moldboards as affected by Soil Moisture Content (SMC) and Forward Speed (FS).

The highest bending moment values for both moldboards were recorded when the soil moisture content decreased to 10.23% at both speeds. The conventional moldboard recorded 157.10 and 160.30 Nm at speeds of 4.96 and 6.20 km h^{-1}, respectively, while the bending moment values for the slatted moldboard were 148.40 and 155.20 Nm at the respective speeds. From this, it can be concluded that the bending moment behaved similarly to the stress values, indicating a direct relationship between them. Thus, an increase in stress on the moldboard was accompanied by an increase in the bending moment, especially for the conventional moldboard. This correlation is due to the same reasons discussed in the stress results, where the stress and resistance experienced by the moldboard are reflected on the shank holding the moldboard, thereby affecting the bending moment values.

CONCLUSIONS

This study provides a comprehensive evaluation of the structural resilience and operational efficiency of conventional versus locally manufactured slatted moldboards under typical Iraqi farming conditions. Through integrated theoretical (FEM-based ANSYS simulations) and field-based analyses, critical insights into stress distribution, strain tolerance, and bending moment have been established.

Theoretically, the slatted moldboard demonstrated superior stress management, exhibiting 7% lower principal stress and 13% reduced principal strain compared to the conventional design. This advantage stems from its slatted ted geometry, which minimizes soil contact area and allows partial soil passage, thereby reducing cutting resistance. However, the conventional moldboard's continuous surface offered greater structural stability, showing 45% less displacement due to its uniform load distribution.

Field experiments corroborated the influence of operational variables:

- Moisture content inversely affected stress, with both moldboards recording reduced stress at 16% moisture (e.g., slatted 0.182 MPa vs. conventional 0.198 MPa at 4.96 km.h^{-1}).
- Forward speed elevated stress proportionally; higher speeds (6.20 km.h^{-1}) amplified stress values by 4–6% across both designs.
- Bending moment increased under low-moisture (10.23%) and high-speed conditions, though the slatted moldboard consistently outperformed the conventional variant, recording up to 7.5% lower bending moment (e.g., 155.20 Nm vs. 160.30 Nm at 6.20 km.h^{-1}).

These findings highlight a trade-off: while the slatted moldboard excels in minimizing stress concentration and bending forces-promising enhanced durability and energy efficiency - its segmented structure compromises displacement resistance. Continuous improvement of the design of moldboard plough, contributes to reducing agricultural operational costs by minimizing inputs and decreasing the energy required to accomplish soil preparation processes.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the University of Mosul and the College of Agriculture and Forestry, which made this work possible.

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