DEVELOPMENT OF KNIVES LOCALLY MANUFACTURED HAMMER MILL BY USING A FINITE ELEMENT METHOD

Suliman[1], A.EL-R.; W.M. Ibrahim[2]; Y.F. Sharobeem[3] and H.S. Abd-Elrahman[4]

ABSTRACT

The research aim to improve the performance of hammer mill knives by study of some engineering factors concerning on grinding knives. The experiments of this study were carried out during the agricultural seasons from 2008 to 2010 using hammer mill for milling grains and some crops residual in Sakha research Center, Sakha, Kafr El Sheikh Government. The hammer mill used in this study with concave hole diameter of 5mm. The moisture content of grains and crop residual were determined. The original and developed knives from local materials were tested from chemical analysis, hardness and tensile test. These tests were carried out at Central Metallurgical Research Development Institute (CMRDI), Helwan, Cairo. Also the finite element method at applying force on knives to find the maximum stresses and suggest the best shape of knife edge (serrated or smooth) and knife tip thickness, which redused the induced stresses in the knife. The results indicated that; using finite element save time and money and the developed knife has more working life.

INTRODUCTION

The cutting tool in agricultural applications is an essential element in cutting operations for harvesting, crushing or any other cutting processes of plants, it's effective knives faced to more wear. The knife material properties of importance besides hardness are tensile strength, modulus of elasticity and coefficient of friction between knife and the material. Some measure of edge brittleness may be important. The steel used in mower blade may typically have an analysis of C-0.82, Mn-0.51 and Cr-0.12%, the edge area is hardened to 55 to 59 Rockwell C while the centers retain 25 to 35 Rockwell C (**Sverker, 1987)**. Therefore, **Awady et al. (1988)** designed an apparatus which measured the resistance of plant stems for cutting. Measurements and

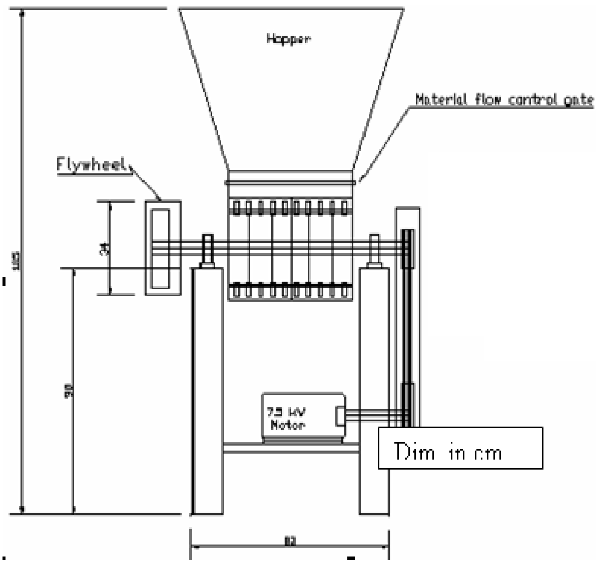
[1]**Supervisor, Agric. Eng. Dep., Fac. Agric., Cairo Univ. Egypt.**
[2] **Assist. Prof. of Agrc. Eng., Fac. Agric., Cairo Univ. Egypt.**
[3] **Chief Res., Agric. Eng. Res. Inst. (AENRI) Research Center Egypt.**
[4] **M. Sc. Student.**

checks were carried out to examine the suitability of the apparatus for the type of work concerned. The results obtained from measurements on artificially wetted lawn, wheat stems and cotton stalks showed significant differences. And they found out, the cutting force is greatly affected by factors as, stalks diameter, moisture content, plant intensity and plant type. **Mohsenin (1970) and Person (1987)** indicated that the cutting process of plant materials in all cases initiates when the edge of the knife firstly makes contact with the material during the continued motion of cutting tool a stress pattern has built up inside the material or stem due to the contact forces and so increases stresses. **Sverker (1987)** mentioned that a grass including small grains and corn (maize) and legumes is the material most commonly involved in agricultural cutting process, so their structure and strength are of special interest. Many grass stems have hallow internodes sections joined be solid nodes. Internodes sections are much weaker than the nodes and thus determine the stem strength. The corn stalk has internodes. **Habib et al. (2001)** cleared that the finite element method is widely used to obtain numerical solutions to partial differential equations. It is used in a variety of industries and engineering disciplines. By using finite element and boundary element (The finite element method is the general numerical technique for frame structures and practical engineering problems) efficient and accurate analysis for hammer mill knife material properties of the impact displacement shape of each node can be calculated to a great accuracy. They also used a finite element analysis of agricultural cutting tools, throughout that found the induced stresses in the cutting tools due to the cutting process and hence their lives are depending on the angle, thickness, and geometry and affected also by the clamping method. They added that tools of straight side-edge shape are of more working life than the tools of other edge shapes (straight mile-edge or serrated edge shapes). **Hamam and Sharobeem (2001)** used a finite element in plow shanks in tillage operation. They found that the local shanks could be made from the local steel37 with less thickness and less weight and adequate factor of safety. The proposed design of the shank with 17 cm width and 2.0 cm thickness will be less in term of weight 33.3 % compared with locally made shank, the reduction in weight will save material and reduce the cost of the local plow. **Mani et al. (2003)** used discrete element method as applied method to model the densification process of biomass 3D software depends on the physical properties of corn stover grinds, used in search hammer mill screen size 3.18 mm at 11% moisture content. **Habib (2002)** said that steel hardness increases by increasing Carbon portion, steel toughness increases by increase Silicon and Molybdenum, the strength increases by increasing Chromium, oxidation resistance increases by increasing Chromium and Molybdenum, increases impact and wear resistance by increasing Vanadium.

The research aimed to improve the performance of the hammer mill knives by study of some engineering factors concerning on the performance of the grinding knives.

MATERIALS AND METHODS

The experiments were carried out by using local hammer mill machine in the workshop of Sakha Reasearch Center, Sakha, Kafr El Shiekh government in 2008 to 2010 seasons. The local manufactured hammer mill as showing in Fig. (1) mainly consists of:



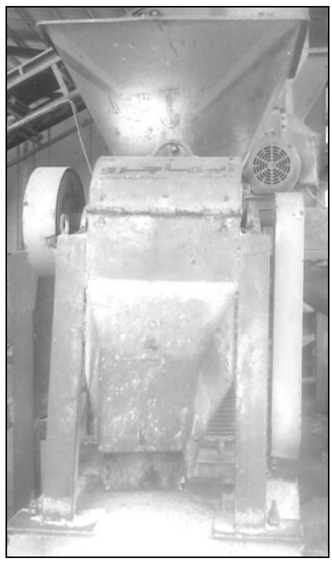


Fig. 1: Hammer mill.

a. Main frame: the main frame of hammer mill has an overall length of 900 mm, width of 830 mm and height of 1250 mm.

b. The hopper: the hopper dimensions are 260 mm width and 500 mm height. The grain hopper feed opening area is 375 cm^2.

c. Rotor shaft: the rotor shaft diameter is 900 mm, was equipped with 45 knives arranged on three bars. The rotor shaft was operated at 44.9 m/s (2200 rpm).

d. Knives: the 45 original knives with edge angle of 10 rad and with the smooth edge. The knives are arranged on three bars each bar has 440 mm length carrying 15 knives. The knives dimension of 80 mm length, 40 mm width, 0.65 and 4mm thickness for smooth and serrated edge knives respectively. The knives made from steel 37. The original knives have two groups have serrated and smooth edges.

e. Develop knives: The developed knives as suggested by the finite element analysis and the locally materials made from spring steel with edge angle of 25rad and smooth edge. The developed knives dimensions are different thickness edges, 80 mm length, 40 mm width and 0.55mm thickness.

f. Concave size: concave sheet of 500 × 725 mm hole diameter from round hole. Each hole has different diameters.

g. Power source: an electrical motor of 10 HP (7.4 kW) is used. It was operated at approximately 28.6 m/s (1400 rpm).

The hammer mill specifications are listed in Table (1). The hammer mill was used to grinding rice straw, corn stover, cotton stalks, corn kernels and corn grains. Each experimental sample is about 60kg of crops. Each sample divided into three groups. The crops moisture content are determined directely before each test and the average of the plant moisture contents are tabulated in table (2).

Table (1): Specifications of hammer mill machine.

Item	Specification	Item	Specification
Rotor diameter, mm	270	AC motor power, kW	7.5
Rotor length, mm	440	Number of knives	45
Rotor shaft speed, $m.s^{-1}$ (rpm)	44.9 (2200)	Knife size (L, W, Th), mm	100, 50, 2.5
Total screen area, cm^2	3332	Knife clearance, mm	12.5
Screen opening dia., mm	5,8,10		

Table (2): The moisture content of crops.

crops	Rice straw	Corn Stover	Cotton stalks	Corn kernels	Corn grains
Moisture content, %	3.23	4.04	7.45	14.2	12.65

The experimental tests are done in split plot design at three replicates to test the knives grinding efficiency using finite element analysis method by program COSMOS/M [Geostar 2.9]. Therefore, the original knives tested before and after used to determine its material type and specifications by chemical analysis, hardness, tensile stress. After that the knives developed using spring steel and previous tested were done again on the developed knives. The program COSMOS/M fed by the resulting of the specific cutting force (P) which calculated using **Dogherty (1982)** equation's (**Habib et al., 2001**).

$$P = \delta \sigma_y + (E/2H)\, h^2 [\beta + \lambda \sin^2 \beta + \lambda \upsilon (1 + \cos^2 \beta)] \quad \text{.........1}$$

Where:

P = Specific cutting force, N/mm.

δ = Knife edge thickness, mm.

σ_y = Yield strength of the plant material.

β = Knife edge angle, degree.

λ = Friction coefficient between knife and plant material.

υ = Poisson's ratio of the plant material.

E = Modules of elasticity of the plant material, N/mm^2.

H = Total thickness of plant material, mm.

H = Instantaneous knife travel, mm.

To evaluate the knives efficiency and the machine performance the following measurements were done:

1. The knives material evaluation were carried out at Central Metallurgical Research Development Institute (CMRDI), Helwan, Cairo.
   a. **Chemical Analysis:** by chemical analysis machines (EDS) it was used to analyzing the chemical of Fe, Ni, Cr, Al, S, Mn, Si, C, Ca, K, Cl, Ca, K, Cl, Na, O, Co, V, Mo, Nb, Ti, W, As and B to decide the knife material type.

b. Hardness testing: by Micro-hardness tester it was used to testing the hardness of the knives, instron 250 kg different inventors, unit (HV) and (HR_C)

c. Tensile test: by tensile testing machines was achieved by load of 5 Mg, work by measurement control system to draw stress, extrusion grapples Haling automatic calibration for used force and sample cut detection, measure strain due to internal stress, unit kg_{f}/mm^2.

2. The knives tested using the finite element analysis to suggest the best knife materials and dimenssions.
3. Evaluation of hammer mill performance as a grinding size distributions.

The selected develop knives material has been carried out using local material to a reasonable cost. Used spring steel material and high value dimensions suggested to the finite element analyses.

RESULTS AND DISCUSSION

The chemical analyses of the knives before and after developed were tabulated in table (3). The data in table (3) cleared that the original knife material has 0.40 % carbon "C" then the developed has 0.78 % "C" that mean increasing knife hardness. Also, the knives contain of 0.10 and 0.26 % chromium "Cr" for original and developed knives respectively. This result due to increasing on knife strength and oxidation "O" resistance. Therefore, by increasing each of Molybdenum "Mo" and Vanadium "V" in developed knife due to increasing both of toughness, knife impact and wear resistance. Theses result agreement with **Habib (2002).**

Table 3. Chemical analysis for knives material:

Chemical components	Fe	Ni	Cr	Al	S	Mn	Si	C
Original knives	91.0	1.0	0.1	0.3	0.5	0.1	0.93	0.4
Modified knives	Bal.	0.021	0.26	0.032	0.0034	0.68	0.22	0.78
Chemical composition	As	B	W	Ca	K	Cl	Na	O
Original knives	----	----	----	0.71	0.73	0.63	0.4	4.2
Modified knives	0.0019	0.0001	0.0073	----	----	----	----	----
Chemical composition	Co	V	Mo	Nb	Ti			
Original knives	----	----	----	----	----			
Modified knives	0.00443	0.0046	0.0008	0.0005	0.001			

2. Hardness

The investigated original knives material is shown in table (4). It was found that the original knives hardness values of 577 and 228 HV for serrated and smooth knives respectively. The results showed that the by using the (HV) hardness the serrated knives has a twice high value than the smooth knives. Then table (4) cleared that the developed knife hardness value of 30 HR_C. This result indicated that the developed knife hardness value (HRc) is the highest from the two shapes of the original knives hardness. The high impact and hardness value helps to use different crop materials.

Table (4): Hardness for original knives material:

<table>
<tr><th colspan="2">Knives</th><th>(HV)</th><th>(HR_C)</th></tr>
<tr><td rowspan="2">Original</td><td>Serrated knives</td><td>577</td><td>----</td></tr>
<tr><td>Smooth knives</td><td>228</td><td>----</td></tr>
<tr><td>Developed</td><td></td><td>----</td><td>30</td></tr>
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3. Tensile Strength Evaluation:

The tensile strength for the knives before and after developed was tabulated in table (5). The data in table (5) cleared that the original knife material has 308.35 MPa for yield strength then the developed has 800 MPa, that mean increasing in yield strength decrease the knife wear.

Table (5): Tensile strength for original and developed knives material:

Knives	Yield strength, (Mpa)	Ultimate Strength, (Mpa)	Elongation, %
Original	**308.35**	**388.20**	**39.66**
Developed	**800**	**965**	**17.5**

4. Finite Element Analysis:

The finite element analysis gets three indicators to determine the knife properties namely stress - material kind and edge thickness. The finite element analysis used to suggest the knife indicators by using the smooth and the serrated knives when used to cut the some crops.

A- The suggested of knives stresses

Using the property of original and developed knives materials and thickness of edge knives by finite element analysis give distributions stresses at grinding crops shown in Figs. from 2 to 5.

Fig. (2) show the stresses distributions on grinding knife for rice straw, corn stover, cotton stalks, corn kernels and corn grains by original serrated edge knives. The figure clear that the maximum stress for rice straw, corn stover, cotton stalks, corn kernels and corn grains are 50110.0, 1.11×10^5, 4.018×10^8, 1.002×10^5 and 4658.0 N/mm^2 respectively while the corresponding minmum stress are 6263.8, $1.395*10^7$, $5.7727*10^7$ 12502 and 5823.4 N/mm^2 respectively.

Fig. (3) clear that the stresses distributions on developed serrated edge grinding knife for rice straw, corn stover, cotton stalks, corn kernels and corn grains by finite element analysis. From the figure it can be shown that the maximum stress are 48206.0, 5.48×10^6, 1.11×10^8, 93175.0 and 4658.0 N/mm^2 respectively for rice straw, corn stover, cotton stalks, corn kernels and corn grains. Meanwhile The minmum stress are 6025.7, 17054.0, $1.395*10^7$, 11647.0 and 472.91 N/mm^2 respectively for rice straw, corn stover, cotton stalks, corn kernels and corn grains.

Fig. (4) illustrate that the stresses distributions on original smooth edge grinding knife for the above crops. The figure show that the maximum stress for rice straw, corn stover, cotton stalks, corn kernels and corn grains are 2.24×10^6, 4.8×10^6, 1.53×10^8, 4.3×10^6 and 4.01×10^5 N/mm^2 respectively. Hence, the minmum stress are 7.131×10^5, 1.196×10^6, 3.492×10^7, 1.291×10^6 and 1.1168×10^5 N/mm^2 respectively for the previous crops.

Fig. (5) show that the stresses distributions on grinding knife for rice straw, corn stover, cotton stalks, corn kernels and corn grains by developed smooth edge knives. From the figure it can be explain that the maximum stress for rice straw, corn stover, cotton stalks, corn kernels and corn grains are 4.03×10^5, 2.46×10^6, 2.07×10^7, 1.2×10^5 and 3.04×10^3 N/mm^2 respectively. Therfore, the minimun values of 96182, 5.56×10^5, 5.37×10^6, 15032, 55150 N/mm^2 respectively for rice straw, corn stover, cotton stalks, corn kernels and corn grains at.

Generally, the results clear that using original serrated edge knives the maximum stress is 4.018×10^8 $N.mm^{-2}$ at cotton stalks while the minimum

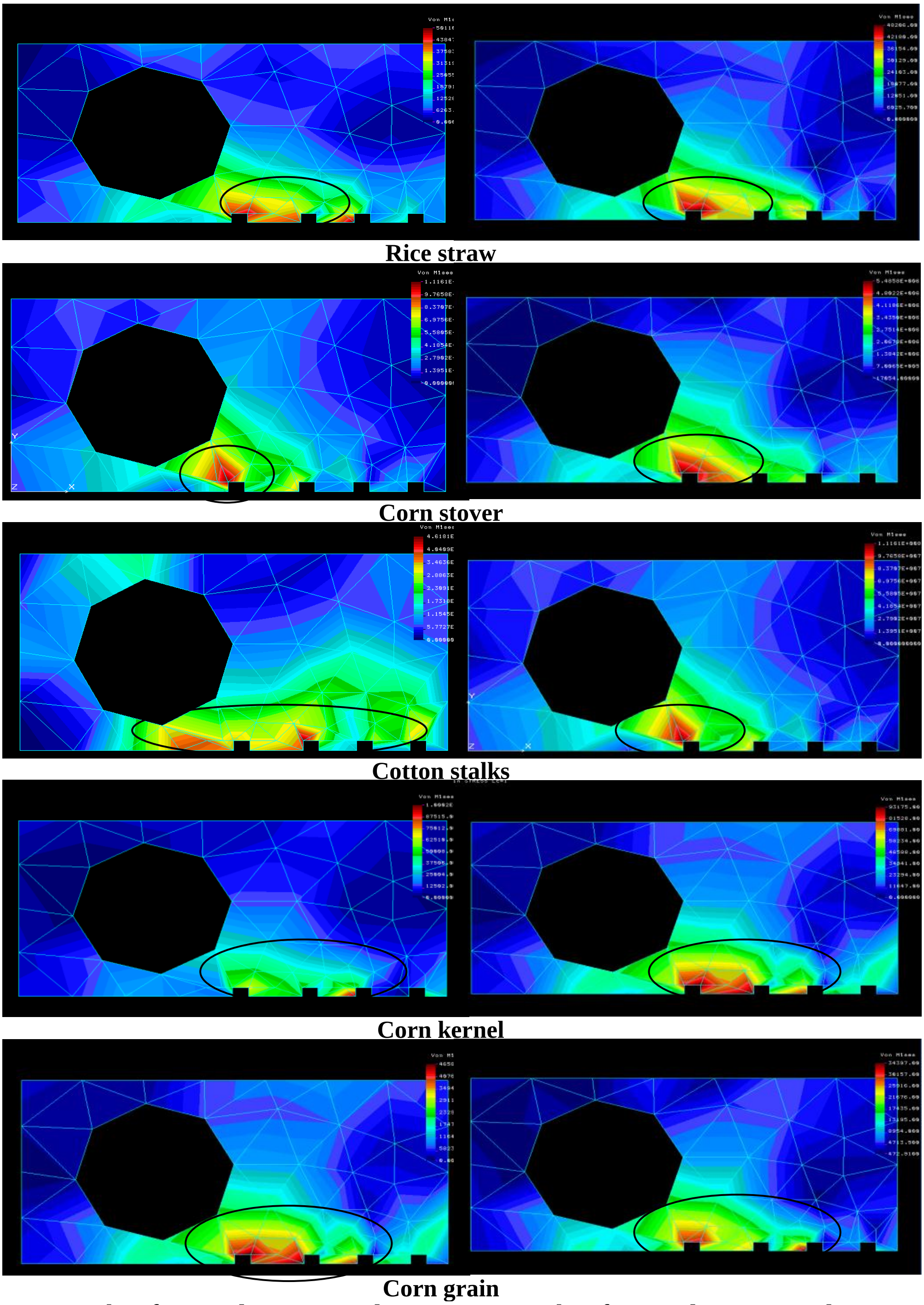

Fig. 2. The finite element analysis on original serrated knife used to grind different crops.

Fig. 3. The finite element analysis on developed serrated knife used to grind different crops.

stress is 5823.4 N/mm^2 at corn grains. On the other had the suggested stress by using Von Mises stress the maximum stress is 1.53×10^8 N/mm^2 at cotton stalks and developed serrated edge while the minimum stress is 472.91 N/mm^2 at corn grains and developed serrated edge. While the binifit knife can be used the smooth knife because of the agricultural residuals need an high stress to cut the fiber materials **Awady et al (1990).**

B- The knives materials and thickness

Table (9) shows that the model of spring steel material is the highest value of stress 2.718×10^6, 4.039×10^5, 4.389×10^6, 2.244×10^6, 1.539×10^8 and 4.846×10^6 kN/mm^2 respectively at grinding rice straw, corn stover, cotton stalks, corn kernels and corn grains. That mean the spring steel material has a high strength compared with the different thickness of steel 37 material.

Fig. (6) shows that the effect of edge thickness on considerable Von Mises stress using original and suggested developed knives. The figure clear that increasing the knife edge thickness from 0.01 to 0.04 mm decreasing the considerable Von Mises stress from 300 to200 for rice straw, 900 to 800 for cotton stalk, 850to 700for corn kernel , 90 to75 for corn grain , 850 to 700 for corn stover and 700 to 580 for bean soya straw kN.mm^{-2}. Consequently, the developed knives have a lower Von Mises stress than the original knives at all knives thickness. It is important to notice that the cutting tools of very sharp knife edges (0.01mm) will undergo high stresses, which cause decreasing of its working life. Conversely, grinding knife of thickness edges (0.02 and 0.04 mm) has a small induced stresses.

Table (9): Variation of Von Mises stress for different edge knife thickness to original and developed.

Material / Thickness, Mm	Maximum Von Mises stress, kN/mm^2 for thickness of knife edge, mm		
	Original (steel 37)		Developed (spring steel)
	0.65	4	0.55
Rice straw	$1.52*10^6$	$81.64*10^3$	$2.718*10^6$
Corn Stover	$7.04*10^7$	$217.3*10^3$	$4.039*10^5$
Cotton stalks	$2.46*10^6$	$234.2*10^3$	$4.389*10^6$
Corn kernels	$4.14*10^7$	$218.4*10^3$	$2.244*10^6$
Corn grains	$4.0159*10^5$	$34.15*10^3$	$1.539*10^8$
Bean Soya straw	$3.06*10^6$	$189.2*10^3$	$4.846*10^6$

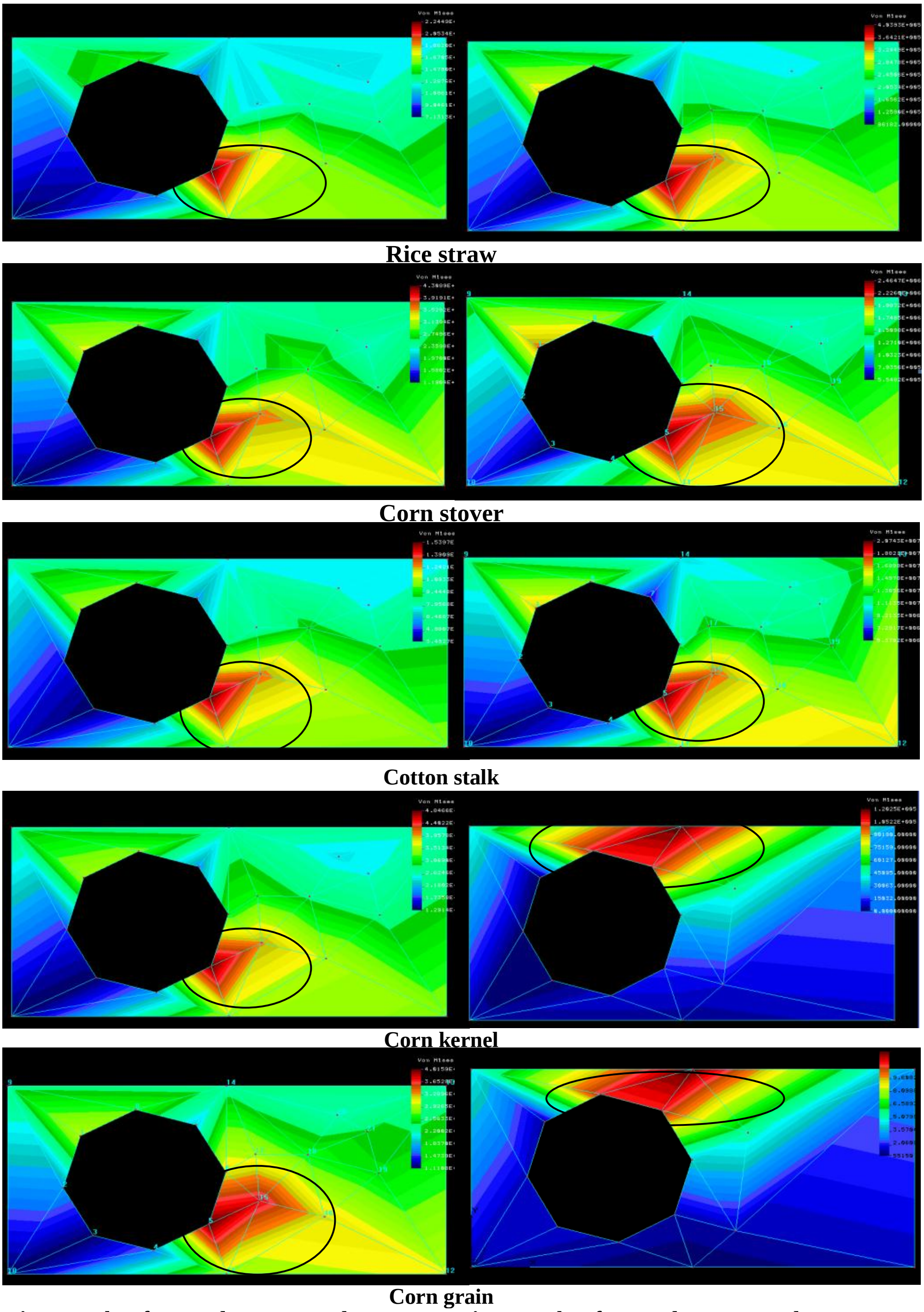

Fig. 4. The finite element analysis on original smooth knife used to grind different crops

Fig. 5. The finite element analysis on developed smooth knife used to grind different crops

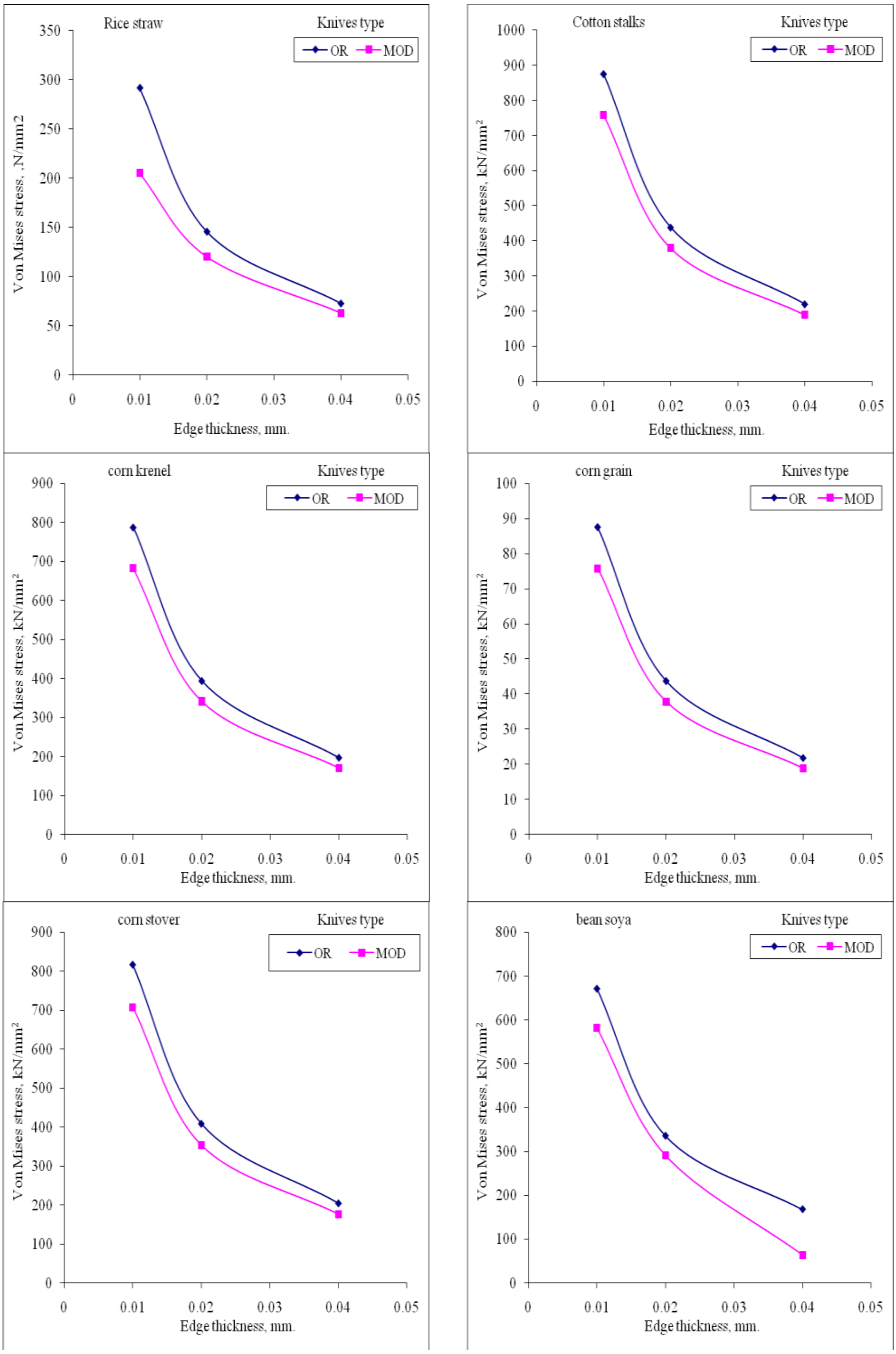

Fig. 6. Variation of Von Mises stress for property different edge knife thickness to original and developed.

5. The Hammer Mill Performance:

a. The grinding percentage using original knife:

Fig. (7) shows that the percentage of less grinding size decreased by increase the screen diameter at different crops residues. The less particle size (< 0.68) percentage was 6, 8, 12, 12, 16 and 16.5 % respectively for corn kernels, cotton stalks, rice straw, soya bean straw, corn stover and corn grains.

b. The grinding percentage using developed knife:

Fig. (8) illustrates the percentage of grinding size the screen of 10 mm was greater than 5 mm screen. For the screen of 10 mm, there was a higher percentage of 62 % concentrated in the sieves bigger that of 3.35 mm size for cotton stalks. While, there was considerably more fine particle of 44 mm in the sieves less than 0.68 mm for the screen of 5 mm and rice straw. The percentage of grinding at sieves less than 0.68 mm ranging from 6 to 7, 8 to 10, 12 to 13, 12 to 16 and 16 to 18 % for corn kernels, cotton stalks, soya bean straw, rice straw and corn stover of 5 mm for the original and developed knives respectively.

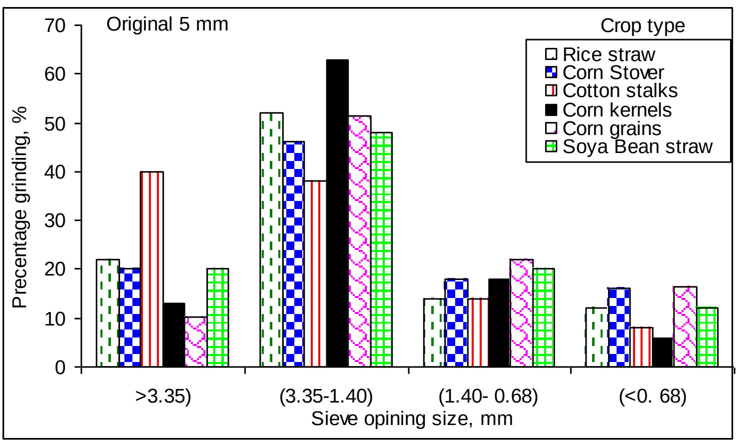

Fig. (7): Grinding percentage using original knife and screen 5 mm.

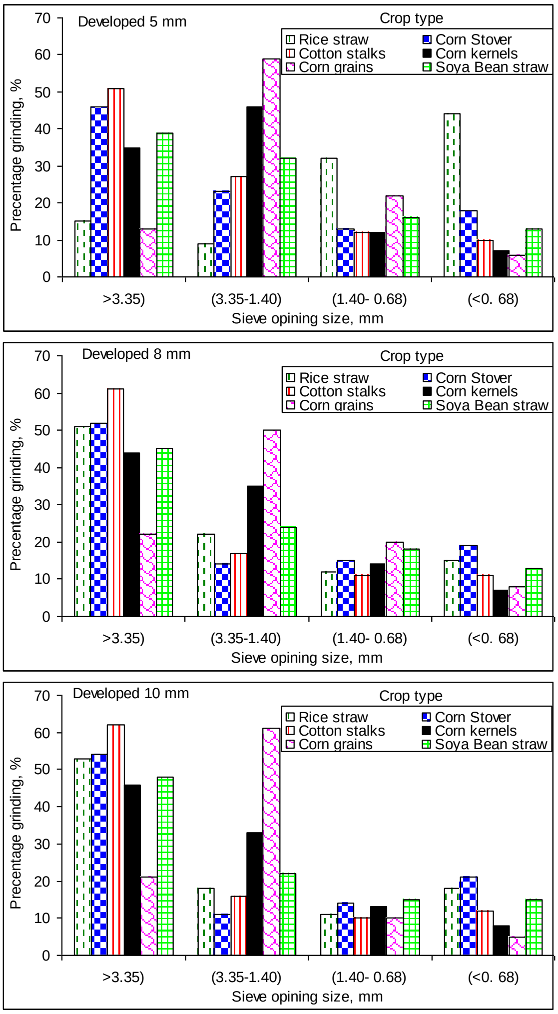

Fig. (8): Grinding percentage using developed knife.

CONCLUSIONS

The research concluded that from the results on the original and developed knives it can be recommended that the developed knife (spring steel) with smooth edge is the affective in strength, oxidation and wear resistance at used to grinding the widely range of the different crops (residual and grains). The developed knives was suggested by finite element analysis is best which high contain of 0.78 % C and 0.26 % cr. Also, it achieve to the maximum stress is 1.53×10^{8} N.mm^{-2} at cotton stalks and the minimum stress is 472.91 N.mm^{-2} at corn grain**s**. Therefore, the percentage of grinding at sieves less than 0.68 mm ranging from 6 to 7, 8 to 10, 12 to 13, 12 to 16 and 16 to 18 % for corn kernels, cotton stalks, soya bean straw, rice straw and corn stover, of 5 mm for the original and developed knives respectively. That meaning the finite element analysis method can be used to suggest the nearly suitable knives materials and dimension. From the research it can be concluded that the developed knives which made from spring steel materials with smooth edge and 0.55mm thickness because it achieved the highest efficiency for widely range of agricultural residuals and grains at using the finite element analysis. These results lead to save in knives material (using less thickness and increase the knives efficiencies about 15%). The results indicated that; using finite element save time and money and the developed knife has more working life.

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الملخص العربى

تطويراسلحة مجرشة محلية الصنع بإستخدام طريقة العناصر المحددة

أحمد الراعى امام سليمان ، وهبه ابراهيم ، يوسف شاروبيم ، هبه عبد الرحمن

تعتبر أداة القطع المستخدمة فى التطبيقات الزراعية العنصر الأساسى فى عمليات التقطيع والفرم والحصاد وهى أكثر الأجزاء عرضة للتآكل لذلك تهدف الدراسة إلى تحسين أداء مجرشة محلية الصنع بدراسة بعض العوامل الهندسية المؤثرة على أداء سكاكين الجرش وتم تصميم وتصنيع سكينة القطع من خامات مختارة ومتوفرة فى السوق المحلى طبقا للخواص الكيميائية والميكانيكية. وقد تم اجراء التجارب العملية خلال موسم ٢٠٠٨ -٢٠١٠ بإستخدام آلة جرش محلية الصنع فى محطة البحوث الزراعية بسخا كفر الشيخ. حيث تم اجراء البحث تحت متغيرات:

١- نوع المنتج النباتى : حبوب الذرة صنف ٣٢٩، صنف فردى ١٠ ،قش الارز، حطب القطن، قش فول الصويا، حطب الذرة، كيزان الذرة.
٢- مواصفات سكاكين التقطيع: شكل الحافة (املس- مشرشر)- سمك الحافة
٣- اقطار الغرابال: ٥، ٨، ١٠مم.

القياسات:

١- قياسات خاصة بمواصفات السكاكين قبل وبعد اجراء التجارب:
أ- قياس اقصى اجهاد – توزيع الاجهادات على السكين باستخدام برنامج العناصر المحددة.
ب- مقاومة الشد – درجة الصلابة - التحليل الكيميائى لخامة السكاكين.
٣- قياسات خاصة بكفاءة الاداء الالى: درجة الجرش.

وقد اجريت الدراسة باستخدام سرعة دورانية للدرفيل (١٤٠٠) لفة/دقيقة وخلوص (١.١٢مم) وثلاث فتحات للغرابيل (٥ – ٨ - ١٠مم) عند رطوبة قش الارز وحطب الذرة وحطب القطن وكيزان الذرة وحبوب الذرة وحطب فول الصويا ٣.٢٣ و٤.٠٤ و٧.٤٥ و١٤.٢ و١٢.٦٥ و٨.٩٥% على التوالى. وقد اوضحت النتائج ان:

اوضح التحليل الكيميائى ان نسبة المواد (الكربون٠.٧٨% والكروم ٠.٢٦% التى تزيد من قوة المقاومة وإنخفاض التأكسد والتآكل أعلى فى السكين المطورة . وكان اقصى اجهاد على السكاكين المشرشرة عند جرش حطب القطن ١.٥٣×10^{8} نيوتن/مم^{2}واقل اجهاد على السكينة ٤٧٢.٩١ نيوتن/مم^{2} عند جرش حبوب الذرة.

ويوصى البحث بإمكانية استخدام السكاكين المصنوعة من خامة spring steel ذات الحافة الملساء وبسمك ٠.٥٥مم بكفاءة عالية ولمدى واسع من المخلفات الزراعية والحبوب بالأبعاد التى تم إقتراحها من برنامج العناصر المحددة لان النتيجة من هذا البرنامج ادى الى توفير فى خامة السكين لخفض السمك المستخدم مع رفع كفائتها بنسبة ١٥% من هنا يمكن القول استخدام برنامج العناصر المحددة يوفر فى الوقت والنقود ويزيد من عمر السكينة.