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Design and Analysis of Manufacturing Methods for Tiller Blades and Threshing Teeth in Bangladesh

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Abstract: Bangladesh is increasing agricultural mechanization to reduce labor-intensive drudgery and to address labor shortages in farming. Agricultural equipment, such as power tillers and threshers, are used to achieve this goal and require regular replacement of the spare parts that experience significant wear in use. Spare parts are currently imported at twice the cost of domestic ones. This paper supports the development of domestic manufacturing by analyzing the manufacturing processes for two fast-moving spare agricultural parts, tiller blades and threshing teeth, and providing a method to develop more efficient processes. The manufacturing processes, which focused on the design of forging and bending dies, reflect the constraints of the manufacturing equipment and stock materials available in Bangladesh. The die designs and manufacturing processes were verified by FEA simulations and by experimental testing. The experiments and simulations suggest that the spare parts should be made at elevated temperatures and high rates of forming. Recommended die designs and processing conditions and forces required to achieve the final part and that can be implemented in manufacturing facilities in Bangladesh are presented.

Keywords: mechanization; agriculture; manufacturing; forging; bending

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1. Introduction

Bangladesh has a population of 166 million people in only 148,460 square kilometers [1]. Forty million people within the country experience food insecurity even though approximately half of the total Bangladeshi industry is agriculture [2]. Currently, farmers in Bangladesh import the majority of the spare parts for their agricultural equipment [3]. High spare part consumption rates, their high cost, and the goal of agricultural mechanization create a prime opportunity to develop efficient domestic manufacturing [3]. Agricultural mechanization increases food production with less drudgery and increased efficiency [3]. Figure 1 shows evidence of increased mechanization by the steady increase in the Bangladesh agricultural spare part market. Increased domestic manufacturing will improve overall manufacturing capabilities as well as the balance of payments in Bangladesh [4]. This paper provides a method to analyze the manufacturing processes used to fabricate two highly consumed, fast-moving agricultural spare parts: tiller blades and threshing teeth [5]. Tiller blades are used by power tillers to turn the soil before planting. Threshing teeth are used by threshers to separate grains from plant stalks. Both pieces of equipment perform crucial agricultural tasks with great efficiency. During use, these components experience wear and need to be replaced. A key feature of Bangladeshi manufacturing is that the majority of its stock material is sourced from salvaged cargo ships beached in the Chittagong region, and hence the composition of which is not well characterized. The overarching goal of the project upon which this paper reports is to make replacement parts for agricultural tools in Bangladesh from local materials, specifically tiller blades and threshing teeth. To support this goal, the material properties of the OEM spare parts used in Bangladesh were determined, effectively reverse engineering their design. This reverse engineering allows the Bangladesh manufacturers to select raw materials from local markets that directly replace OEM spare parts and function equivalently. To provide guidance to Bangladesh spare parts manufacturers, dies and manufacturing processes were designed and analyzed to fabricate these spare parts domestically. This guidance is applicable and beneficial to current and developing manufacturing facilities, often referred to as small to medium enterprises (SMEs) within Bangladesh.

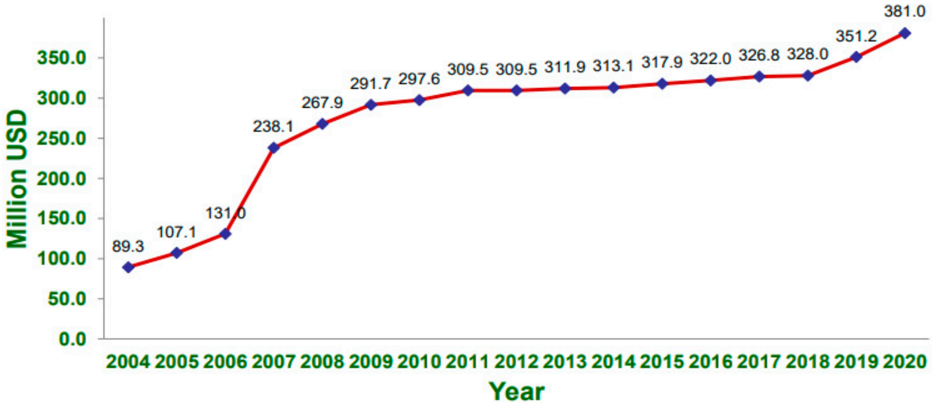


Figure 1. Annual value of the agricultural spare parts market in Bangladesh (USD) [5].

1.1. Tiller Blades

Power tillers are used throughout Bangladesh to prepare soil for planting (Figure 2a). Tiller blades are used to prepare the soil for planting. Figure 2b shows the tiller blades studied in this article. The blade is mounted with nuts and bolts through its mounting holes to the rotating shaft of the power tiller.

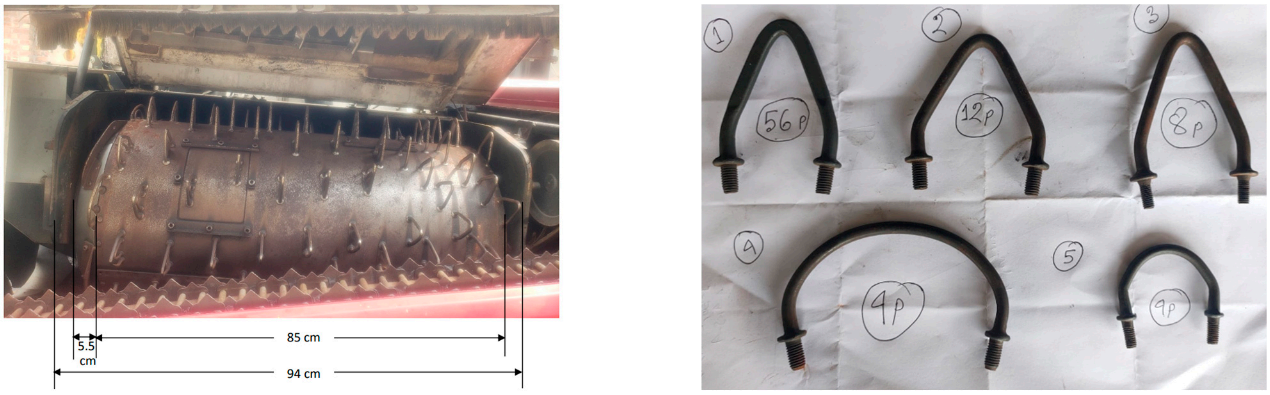
(**a**)

(**b**)

Figure 2. (**a**) Power tiller preparing soil in Bangladesh. (**b**) Tiller blades studied in this research.

1.2. Threshing Teeth

The threshing teeth studied in this article are used in a Yanmar combine harvester shown in Figure 3a, which depicts the threshing barrel assembly, its teeth, and its overall dimensions. The teeth are installed on a barrel that rotates rapidly as stalks of wheat, rice, soybeans, or other grains are fed perpendicular to the barrel and release and separate grain from the stalks. Various threshing teeth designs are shown in Figure 3b. Each of the designs has a specific purpose and they are installed in tandem along the threshing barrel to provide accurate amounts of threshing. The designs analyzed in this article are labeled "1" and "3" in Figure 3b. The tooth labeled "1" in Figure 3b has forged flats present on the arrow-shaped bent portion to perform a cutting operation. The tooth labeled "3" in Figure 3b is a similar design with a thinner diameter and no flats present. The teeth may be bolted or welded onto the barrel; the former are analyzed here.



(**a**) (**b**)

Figure 3. (**a**) Thresher teeth installed on a barrel of a Yanmar combine harvester with dimensions in centimeters. (**b**) Five different designs for threshing teeth.

2. Materials and Methods

2.1. Manufacturing Methods

By reverse engineering the tiller blades shown in Figure 2b, potential manufacturing processes are proposed and tabulated in a morphological chart. A morphological chart is a theoretical list of the manufacturing steps and techniques that could be used to generate a final product. These processes incorporate the constraints found within the manufacturing facilities in Bangladesh, including labor availability and age of equipment. The processes are presented in Table 1 from left to right in order of decreasing manufacturing time or increasing volume of parts to be produced. First, the 2-dimensional geometry is cut from flat stock material. These operations depend on the shape of the input stock metal. A long, flat bar requires shearing, but a flat plate is best cut by plasma cutting. If the mounting holes are not cut at the same time as the perimeter geometry, they are cut in a secondary step. Next, the workpieces are heated to between 600 °C and 700 °C to reduce the processing forces and hence die stress. Then, the sharp edge is forged onto the flat workpiece. Next, the flat blade is bent to the desired angle. The final two steps are quenching and hardening and painting the part to improve wear resistance and appearance. Care needs to be taken to ensure that the hardening process does not make the final part too brittle, or it will prematurely fail in use.

Table 1. Morphological processes for manufacturing tiller blades.

Feature	Process 1	Process 2	Process 3
Planar Geometry	Shear	Plasma Cutting	Blanking
Mounting Holes	Drill		
Heating		Furnace	
Sharp Edge	Grinding	Forging Press	
Angled Bend		Bending Die Forging Press	
Quenching/Hardening		Water/Oil Bath	
Painting		Powder Spray Painting	

By similarly completing the reverse engineering process on the Yanmar OEM threshing teeth, two sets of feasible morphological processes are generated. The processes are presented in Table 2 from left to right in order of increasing volume of parts produced. First, the cylindrical rod workpieces are cut to length. Second, the workpieces are heated to at least 600 °C to reduce the force required in the bolt head forging operation and ease the removal of the workpiece from the dies. Third, the bolt head flange is formed at both ends of the straight workpiece. Fourth, the ends above the flanges on the straight workpiece are threaded, ideally on a cooled workpiece. A note can be made that no matter which threading process is used, the workpiece must be at room temperature for the operation. The workpiece also must be straight (unbent) for threading. The fifth and sixth steps are to reheat the workpiece and then perform the bending operation. To reduce die wear, it is recommended that the bending process take place with a workpiece at an elevated temperature. If flats are required on the final geometry, there is an additional forging step following bending using the same equipment used in bolt head forging. Quenching/hardening can be performed in a seventh step to strengthen the part and improve its wear resistance if desired. Care needs to be taken to ensure that the teeth are not too brittle for use after hardening. The last step is painting for additional wear resistance and appearance.

Table 2. Morphological processes for manufacturing threshing teeth.

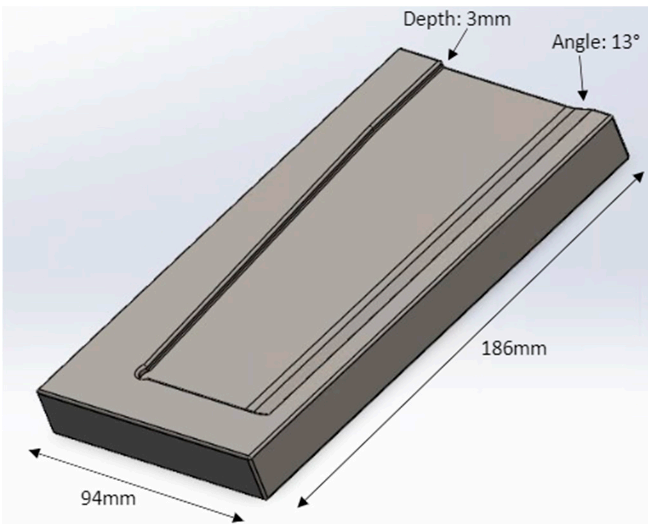
Feature	Process 1	Process 2
Cutting to Length	Angle Grinder	Shear
Heating	Furnace	
Bolt Head Flange	Forging Press	
Threads	Lathe (Die or Indexable Insert)	Thread Rolling Dies
Heating	Furnace	
Angled Bend	Forging Press	Press Brake
Forging Flats [1]	Forging Press	
Quenching/Hardening	Water/Oil Bath	
Painting	Powder Spray Painting	

[1] Operation only required for cutting tooth design with flats.

2.2. *Design of Bending and Forging Dies*

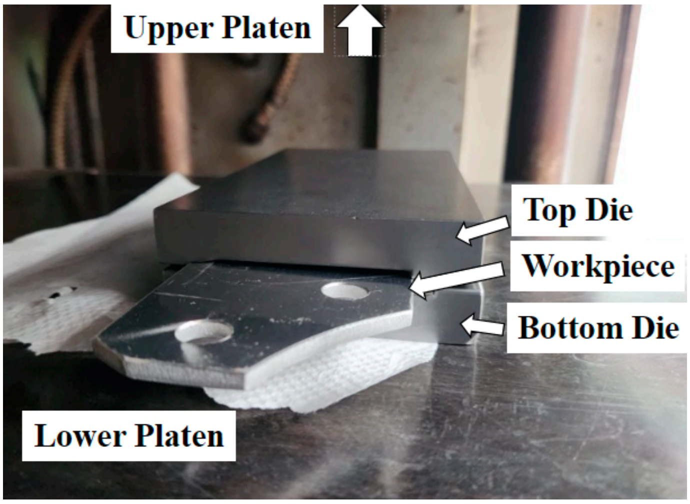
2.2.1. Tiller Blade Sharp Edge Forging Dies

One of a set of tiller blade sharp edge forging dies is shown in Figure 4a. The dies are manufactured from as-received ASTM A36 steel and case-hardened to 66 Rockwell hardness C (HRC) to provide additional strength. As the dies close, the workpiece is forged between the two angled portions, which form the sharp edge. The angled portions of the dies are set at 13° with respect to their faces to create a 26° angle for the sharp edge.



(**a**)

Figure 4. *Cont.*



(**b**)

Figure 4. Tiller blade sharp edge forging dies: (**a**) drawing (**b**) photograph of apparatus.

2.2.2. Tiller Blade Bending Dies

The tiller blade bending dies compress the workpiece to bend it as shown in Figure 5. The dies are machined from ASTM A36 steel and are not heat-treated due to the minimal die stress experienced. More details can be found in reference [5].

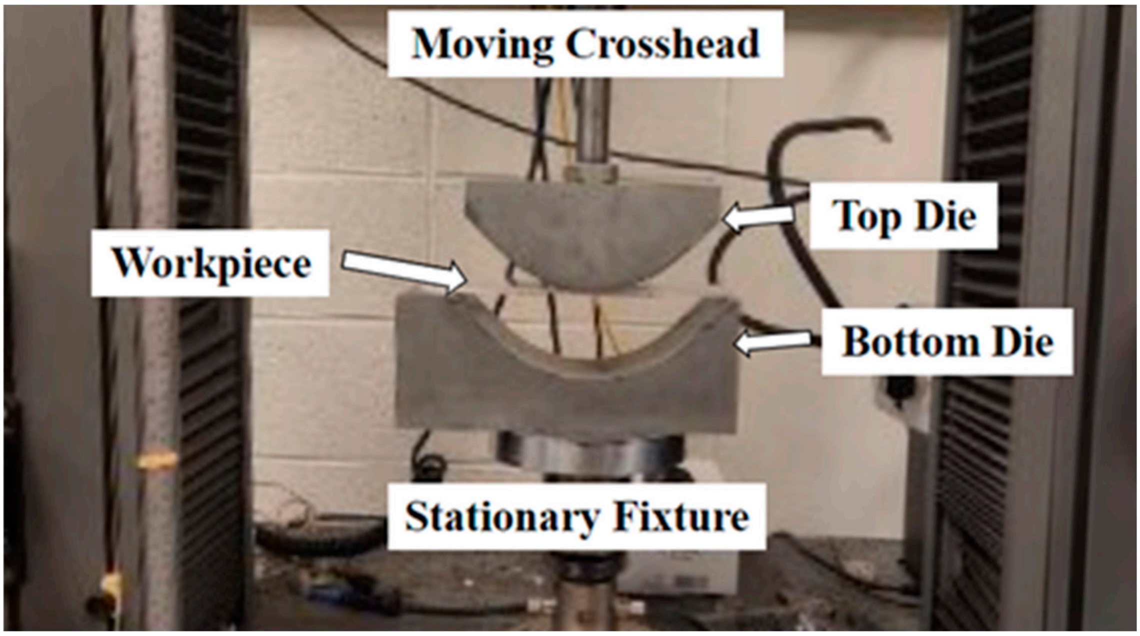
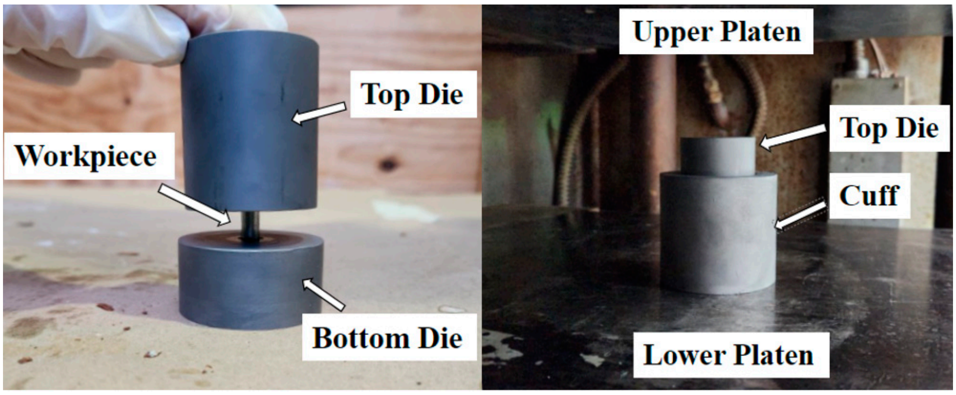


Figure 5. Tiller blade bending apparatus.

2.2.3. Threshing Teeth Bolt Head Forging Dies

The threshing teeth bolt head forging dies are machined from AISI A2 tool steel and hardened to 52.4 HRC for additional strength [5]. Figure 6 presents the forging dies and the cuff used to align the top and bottom dies. Both dies contain tapered cavities to form the head and flange and enable part removal. The top die also includes a through hole in its center for an ejector pin to remove the part, which expands and jams during forming.



(**a**) (**b**)

Figure 6. Threshing tooth bolt head forging apparatus (**a**) dies with workpiece and (**b**) dies with cuff.

2.2.4. Threshing Teeth Bending Dies

The bending die apparatus for the threshing teeth are machined from AISI A2 tool steel and are shown in Figure 7. They are not heat-treated because the properties of the as-received metal are adequate. The bottom die has a radial notch machined across its top horizontal surface to prevent the workpiece from rolling off the die.

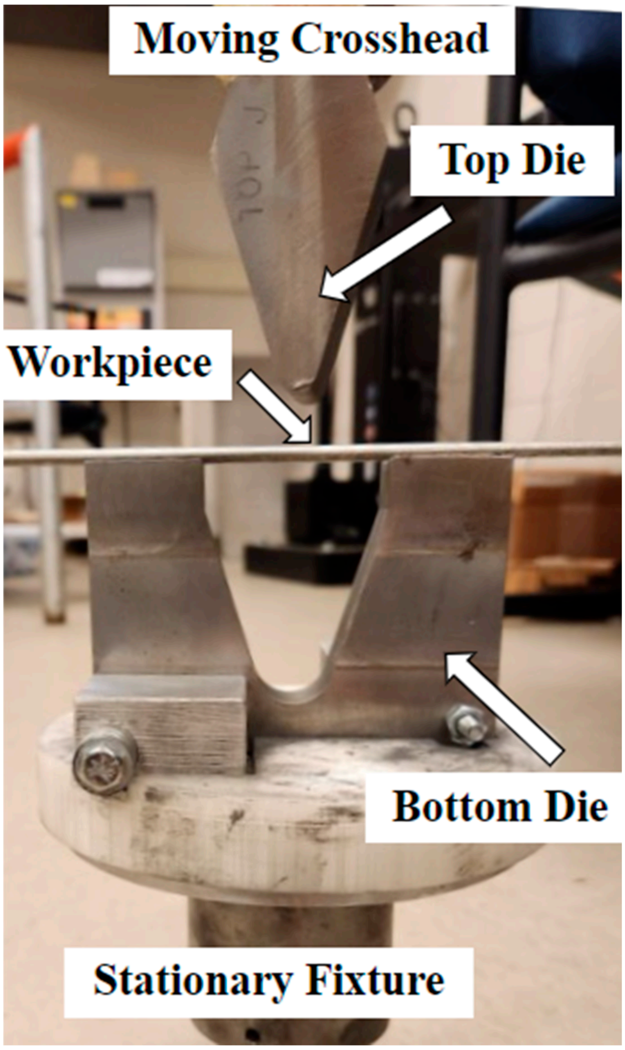


Figure 7. Threshing tooth bending apparatus.

2.2.5. Threshing Teeth Flats Forging Dies

Flat plates are used to produce the flat features on the angled portion of the threshing teeth. The forging dies are shown in Figure 8. The top die is a flat piece of steel. The bottom die is also flat and incorporates a 2-mm deep ridge that serves as a locator to ensure that the same amount of each tooth is forged each time. Both the top and bottom dies are made from as-received AISI A2 tool steel without hardening.

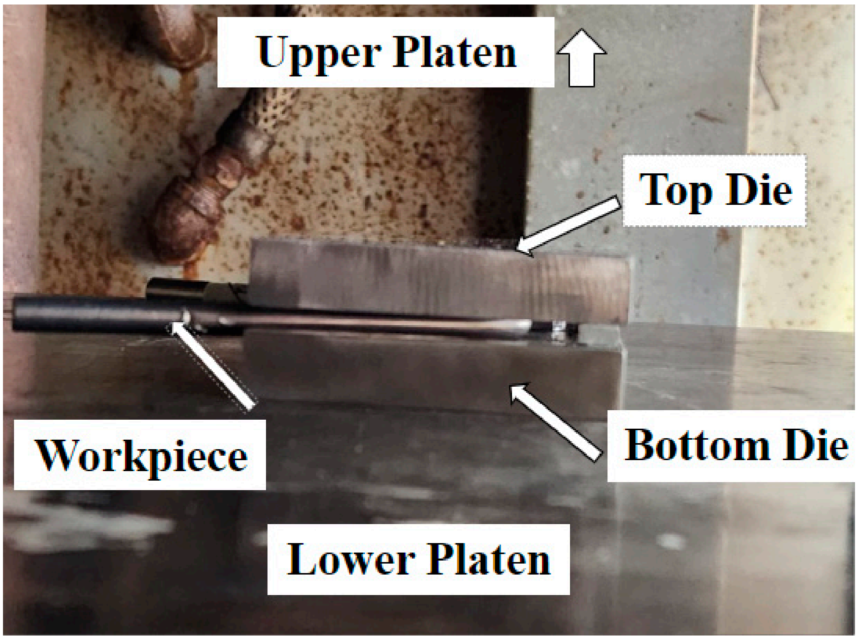


Figure 8. Threshing teeth flat forging apparatus.

2.3. FEA Simulations and Parameters

The bending and forging operations are simulated and analyzed with the DEFORM software (Version 11.1 published by Scientific Forming Technologies Corporation, Columbus, OH, USA) using the Multiple Operations 2D/3D layout with the 3D Forming Multiple Operations preprocessor [6]. DEFORM is a finite element analysis (FEA) software specifically designed to simulate manufacturing techniques such as bending, forging, and machining. After importing the geometry for the workpiece and dies generated in SolidWorks (Dassault Systems, 2023) [7] as STL files and applying a predetermined mesh size, the movement, material, temperature, boundary conditions, friction coefficients, and step sizes need to be applied. Table 3 presents the materials used for the FEA simulations, the experiments, and the materials from which the actual parts are made.

Figures 4–8 provide visualization of the loading conditions, rather than provide drawings of the mesh elements. Since DEFORM is a well-proven commercial software, it was not felt it was necessary to provide details of the FEA itself. Further details on the FEA can be found in reference [5]. These figures also show the design of the dies that are analyzed, which provide Bangladesh manufactures templates to fabricate their own dies.

The DEFORM parameters vary slightly depending on the deformation operation being performed. First, a note on the metals used in Bangladesh. These are sourced from salvaged ships, which are broken up on the beaches of the Chittagong region of Bangladesh and then are sold in local markets without any analysis for metal alloy. As a result, they are not available in the USA for testing or in the DEFORM FEA material library. Therefore, the closest metals to the Bangladesh metals for the USA experiments and from the DEFORM FEA material library were used. For the simulations modeling the experimental conditions for the tiller blades, both AISI 1100 aluminum and AISI 304 stainless steel were used for the sharp edge forging and bending operations, respectively. AISI 1100 aluminum was used as a room temperature stand-in for steel processed at elevated temperatures because elevated processing temperatures were not available at Georgia Tech for sharp edge forming. AISI 1100 was selected because its mechanical behavior (flow stress) at room temperature matches AISI 304 stainless steel at elevated temperatures and elevated processing, which in turn matches the actual material used to make the blades, AISI 1043 carbon steel, which was not available in the Georgia Tech laboratory or in the DEFORM material library. The lubricated frictional coefficients for these operations that were performed at room temperature (20 °C) were 0.15. For realistic manufacturing recommendations using AISI 1043 carbon steel, the lubricated friction coefficients were 0.2 for 700 °C workpieces and 0.15 for 1000 °C workpieces. The friction coefficients were determined according to the lubrication method used, temperature of the workpiece, and materials at the interface based on a literature review conducted using the following references [8–17]. The simulated deformation operations for the threshing teeth were performed using AISI 4140 steel as the material for both the experimental comparison simulations as well as the manufacturing recommendation simulations. AISI 4140 steel is the material from which the actual threshing teeth are made. The frictional coefficients were 0.15, 0.2, 0.2, and 0.15 for the 20 °C, 600 °C, 800 °C, and 1000 °C workpieces, respectively. AISI 4140 steel was not available at Georgia Tech; therefore, AISI 1018 steel was used as a stand-in due to its similar processing properties and its availability in the DEFORM material library. An isotropic, rigid–perfectly plastic, non-strain hardening material model was used for the parts being fabricated. The dies and fixtures were assumed to be rigid. The speed of die closure was determined by the equipment being simulated. For the Wabash press used at Georgia Tech, the platen closing speed was found to be 10 mm/s for the forging operations. The maximum speed was set at 1 mm/s for the Instron fixture used for the bending operations at Georgia Tech. To emulate the manufacturing setting, the simulations performed at manufacturing standard conditions used a speed of 100 mm/s, which is an average speed for typical manufacturing equipment. The additional settings including the mesh size and step size for die movement can be found in Table 4. Mesh convergence studies can be found in reference [5]. The results of the FEA tests are presented in Section 3.

Table 3. Materials used in FEA simulations and experiments.

Part	Operation	FEA Material	Experimental Material	Actual Part Material
Tiller Blade	Sharp Edge Forging	AL 1100, AISI 304	AL 1100	AISI 1043
	Bending	AISI 304	AISI 304	AISI 1043
Threshing Tooth	Bolt Head Forging	AISI 1018	AISI 1018	AISI 4140
	Bending	AISI 1018	AISI 1018	AISI 4140
	Flat Forging	AISI 1018	AISI 1018	AISI 4140

Material was sourced from McMaster-Carr, Douglasville, GA, USA.

Table 4. DEFORM simulation settings for each deformation operation.

Part	Deformation Operation	Number of Elements	Step Size (mm/s)
Tiller Blade	Sharp Edge Forging	140,000	0.02250
	Bending	140,000	0.07625
Threshing Tooth	Bolt Head Forging	90,000	0.09750
	Bending	50,000	0.18500
	Flat Forging	90,000	0.01500

2.4. Experimental Materials and Equipment

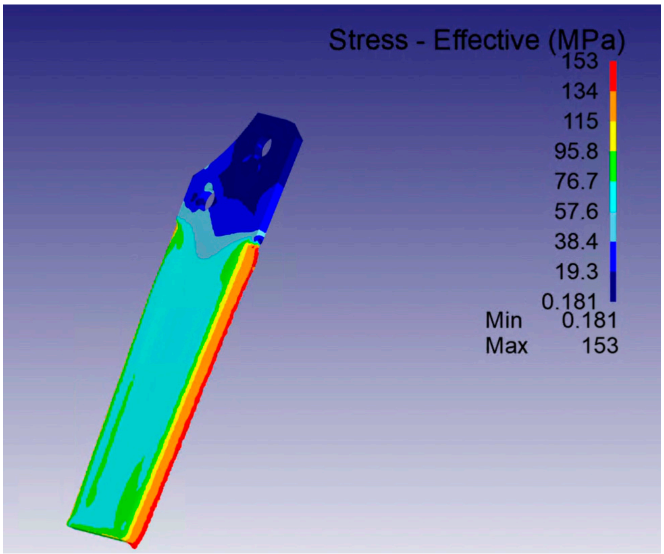
Experimental bending and forging experiments were completed to validate the accuracy of the FEA simulations. A Wabash 45 metric ton hydraulic heat press, Model #20-1212-2TMX (Wabash, Inc., Lafayette, IN, USA) and a 100 kN Instron, Model #5982 (Instron, Norwood, MA, USA) were used for the forging and bending deformation operations, respectively. Hi-Temp C-100 Molybdenum Disulfide Anti-Seize Lubricant, Part # 51017 (Fel-Pro, Inc., Skokie, IL, USA) was used as the lubricant for all tests. The tiller blade sharp edge forging operation was performed using annealed 5-mm thick AISI aluminum 1100 H-14, and the forces applied were from 20.7 to 32.0 Metric Tons. The tiller blade bending experimentation was completed using 5-mm thick AISI 304 stainless steel with forces applied from 20 to 80 kN at 20 kN intervals. The experiments for the threshing teeth used 6-mm diameter AISI 1018 steel rods. The bolt head forging operations were performed on a 600 °C workpiece at forces from 0.9 to 22.8 Metric Tons. The threshing teeth bending operations were performed at forces from 30 to 75 kN at 5 kN intervals. Lastly, the flat forging operations were performed from 20 to 50 kN at 10 kN intervals. The results of the forming tests are presented in Section 3. Except for the bolt heading operation, the tests were performed at room temperature.

3. Results and Discussion

3.1. Tiller Blades

3.1.1. Edge Forging Simulation and Experimental Comparison

Figure 9 shows an example of FEA results for the tiller blade sharp edge forging for AISI 1100 aluminum 5 mm thick at 20 °C and the resulting formed blade. The stress shown in Figure 9a is the effective von Mises stress is provided solely to assist the reader in visualization of the stress state. The simulated and experimental values of the forging forces, which are shown in Figure 10, are used to provide guidance to manufacturers in Bangladesh as discussed below. Figure 10 compares the FEA simulations to the experimental results. The sharp edge forging dies performed well in both the simulations and experiments generating accurate final part geometry with a final sharp edge thickness between 1.1 mm and 1.4 mm. Figure 10 shows a 15% average difference between the thicknesses produced by the simulations and the measured experimental results at the same force applications. This deviation is a result of slight die displacement in the horizontal plane during forging. This movement can be resolved by fixturing the dies onto a dedicated piece of manufacturing equipment as they would be in a realistic manufacturing setting. The slight flattening of the curve between 26 and 28 tons could be due to inconsistencies of the thickness of the sharp edge and of the length of that edge being forged. Slight changes in those dimensions would affect the forging force because force equals stress times area.



(**a**)

Figure 9. *Cont.*

(**b**)

Figure 9. Tiller blade sharp edge forging for AISI 1100 aluminum 5 mm thick at 20 °C (**a**) FEA results effective von Mises stress. (**b**) Resulting formed blade.

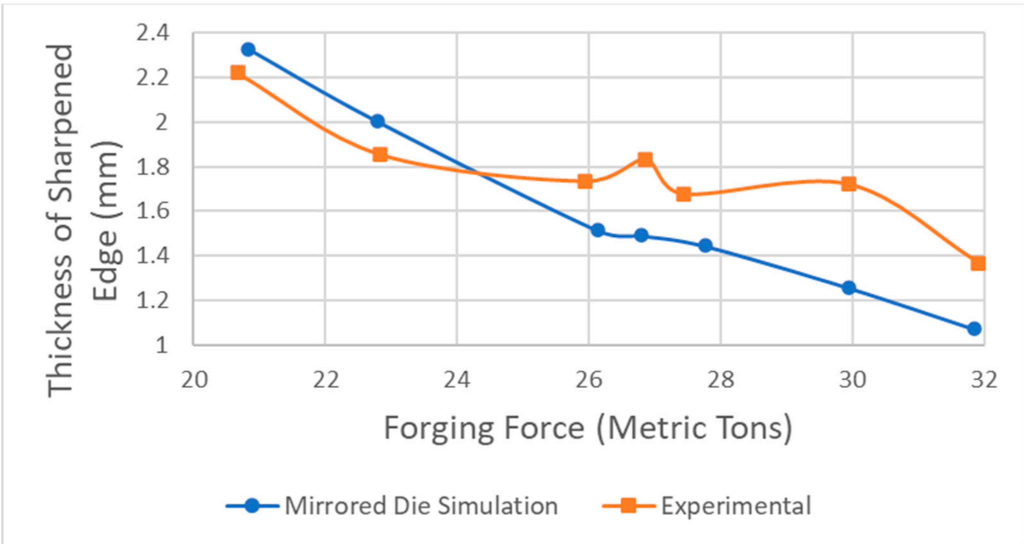
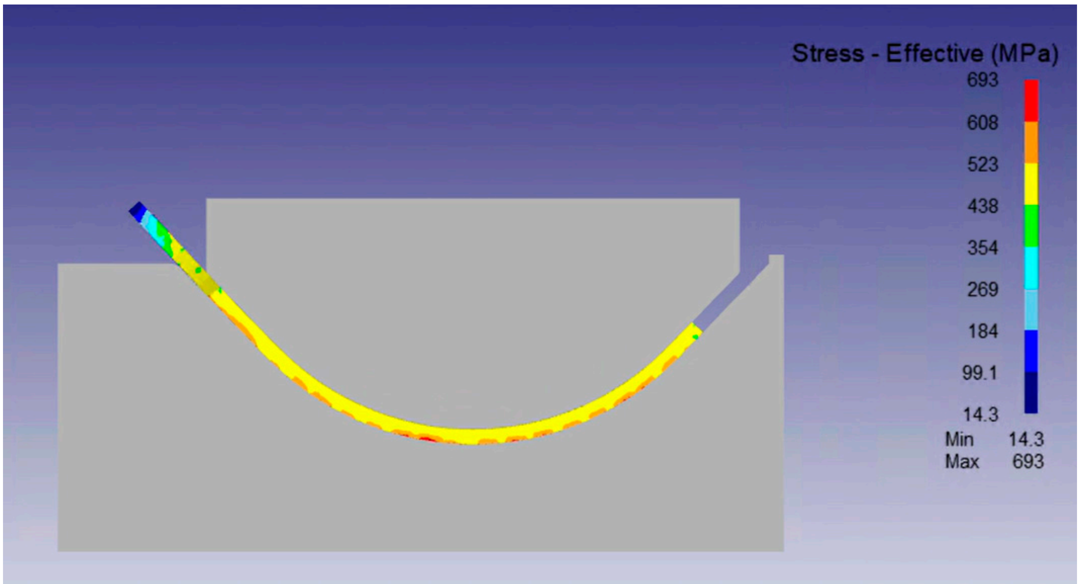


Figure 10. DEFORM simulation and experimental results for lubricated sharp edge forging operation on AISI 1100 aluminum at 20 °C at the same force application measuring the thickness of the blade.

3.1.2. Bending Simulation and Experimental Comparison

Figure 11 shows an example of the FEA simulation of the tiller blade bending operation and the resulting blade. Figure 12 compares the bending simulations and experimental results for the tiller blade using AISI 304 stainless steel material. There is a smaller percent difference (11%) when comparing the simulation and experimental results for the inner angles of the final bent workpiece. This deviation is due to the surface contact that occurs during the forging portion at the end of the bending deformation. The forging force plastically deforms the workpiece almost exactly to the geometry of the dies and produces more uniform final workpieces with less springback. An example of this forging force for an AISI 304 stainless steel workpiece is shown in Figure 13 as the force approaches 60 kN at 57 mm of displacement. The simulation underestimates the springback. This may be due to several reasons. One reason is that the amount of forging performed during experiments is less than during the simulation. It is known that forging at the end of a bending process reduces springback. Another reason may be the difference between the actual material and the material in the DEFORM material database. A third reason could be the difference in lubrication between the simulation and the experiments. One note is that Figure 13 starts at 10 tons because forces below 10 tons do not provide measurable or appreciable deformations.



(**a**)

(**b**)

Figure 11. Tiller blade bending. (**a**) Finite element analysis effective von Mises stress. (**b**) Resulting bent blade.

3.1.3. Tiller Blade Manufacturing Recommendations

With the verification of the tiller blade forging and bending simulations through experimentation and explanation of the sources of error and their remedies, Tables 5 and 6 present recommendations for manufacturing AISI 1043 carbon steel tiller blades in a Bangladesh manufacturing setting. Safety factors of 1.5 are included in the recommendations, which can be modified as desired. Forging forces, as seen in Figure 13, should be applied at the end of the bending operation to eliminate spring back and increase the uniformity and accuracy of the final angle.

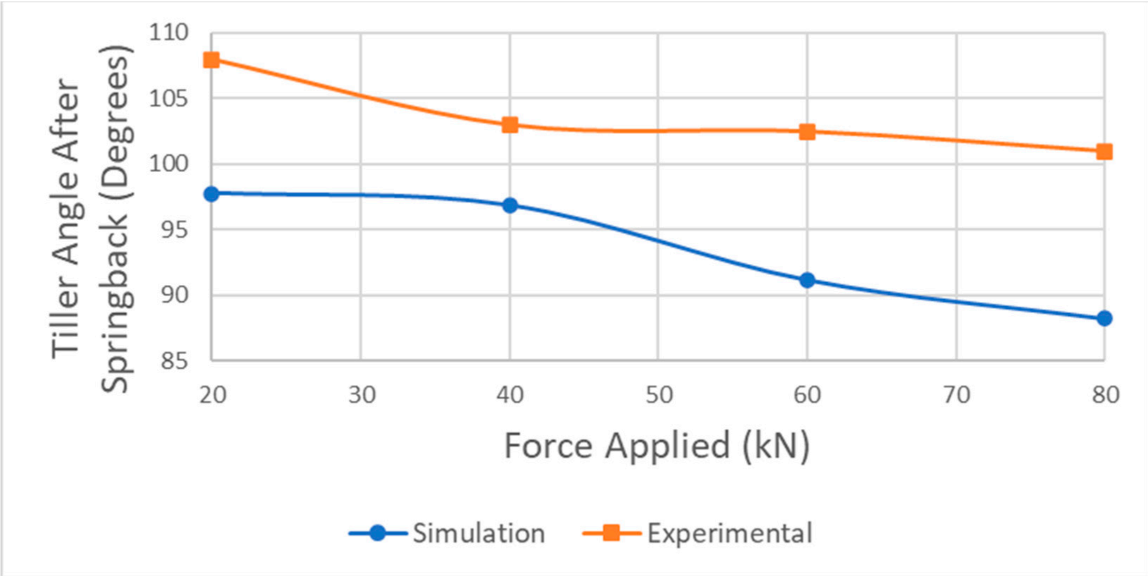


Figure 12. DEFORM simulation and experimental results for the bending of AISI 304 stainless steel tiller blades.

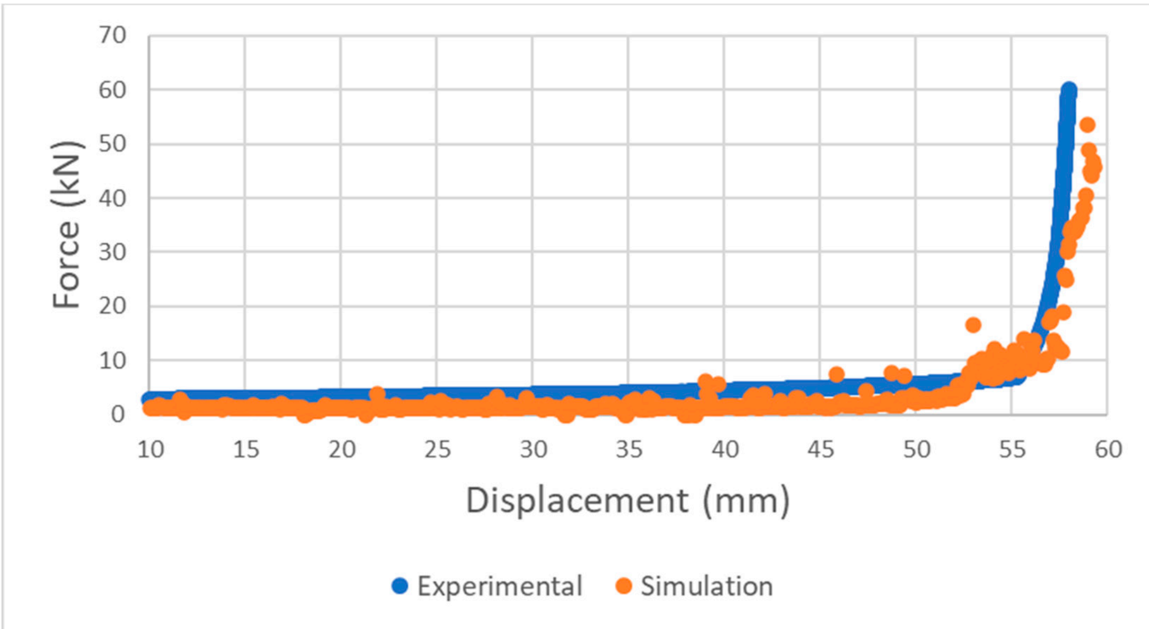


Figure 13. DEFORM simulation and experimental results for AISI 304 stainless steel tiller blade forged to 60 kN after initial lower bending forces.

The manufacturing recommendations presented in Tables 5 and 6 are feasible in the manufacturing facilities at Bangladesh. Furnaces for heating the workpieces are commonly used for manufacturing processes in the country. The drastic reduction in forces from using heated workpieces ensures that existing or future purchased equipment with the proper capacity is available. The sourcing of stock material from beached ships does not hinder the feasibility of these proposed manufacturing processing recommendations. If a material dissimilar to those analyzed in this article is used, the same FEA simulation analysis can be replicated using that material's properties to find new processing recommendations. Further, the proposed dies have been shown to be appropriate for manufacturing these parts.

Table 5. Recommended processing conditions to forge the sharp edge on AISI 1043 carbon steel tiller blades with lubrication.

Temperature (°C)	Force Required (kN)	Force Required w/SF of 1.5 (kN)	Die Stress (MPa)
700	1376	2064	993.0
1000	503.2	754.8	351.0

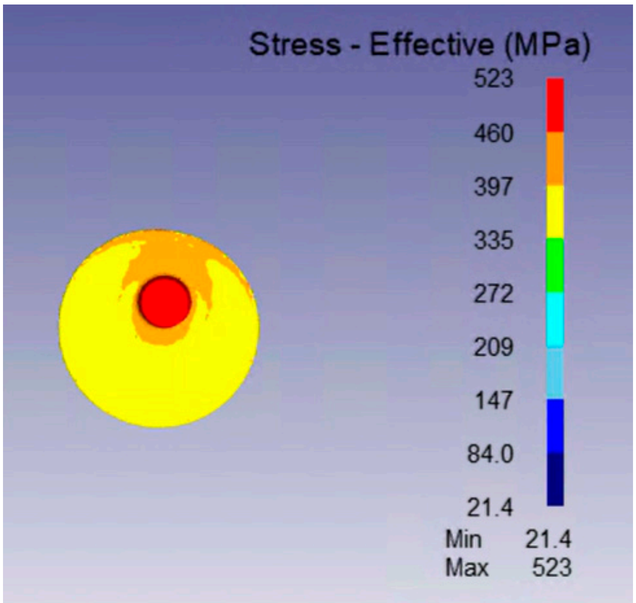
Table 6. Recommended processing conditions to bend the AISI 1043 carbon steel tiller blades with lubrication.

Temperature (°C)	Force Required (kN)	Force Required w/SF of 1.5 (kN)	Die Stress (MPa)
700	22.64	33.96	67.90
1000	8.262	12.39	28.30

3.2. Threshing Teeth

3.2.1. Bolt Head Forging Simulation and Experimental Comparison

Figure 14 shows a representative FEA simulation and an experimental result. The latter image shows the result of a misalignment of the dies, which the application of the cuff reduced. The bolt head forging operation results for the simulations and experiments are found in Figure 15. As expected, an increase in the applied force leads to a decreased flange thickness. There are large differences in the flange thicknesses between the simulation and experimental results at lower forces, but those discrepancies lessen with increasing forces applied. At forces below 11 kN, the flange thickness experiences a more dramatic negative trend with respect to higher forces. At forces higher than 11 kN, the flange thickness begins to level out. This is due to greater surface contact area of the flange with the flat faces of the dies that results in higher frictional forces that need to be overcome. At and above 11 kN, the percent difference reduces to an average of 37% from 46%. As the final flange thicknesses should be limited to between 1-mm to 2.5-mm, the larger discrepancies at lower forces are of little concern.



(**a**)

Figure 14. *Cont*.

(**b**)

Figure 14. Thresher tooth bolt heading operation for 6-mm diameter AISI 1018 steel. (**a**) FEA result effective von Mises stress. (**b**) Resulting forged part showing effect of misalignment of dies.

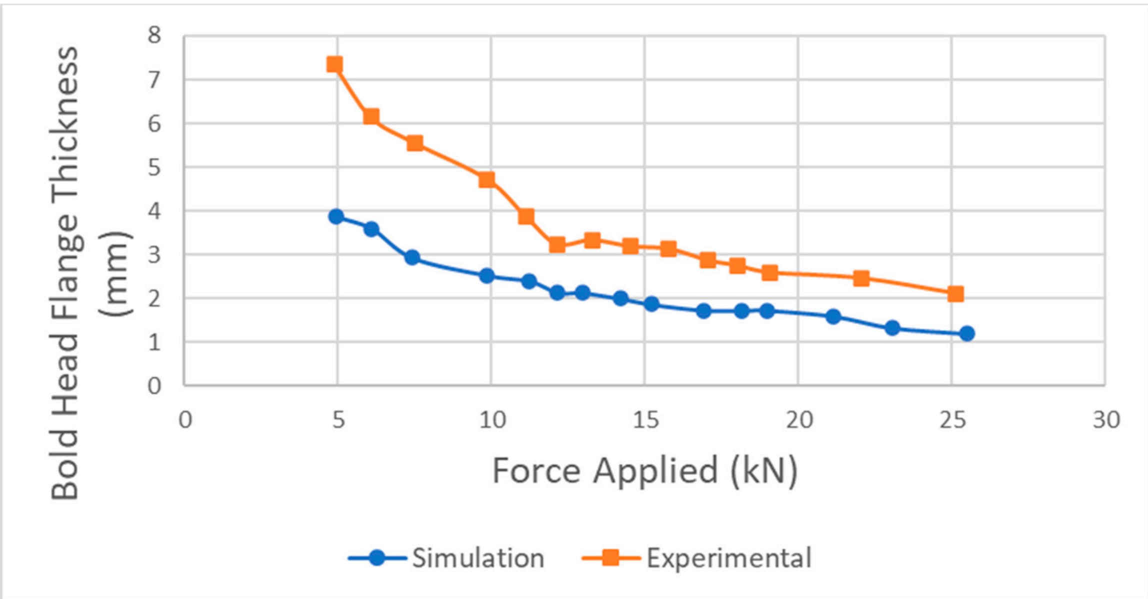
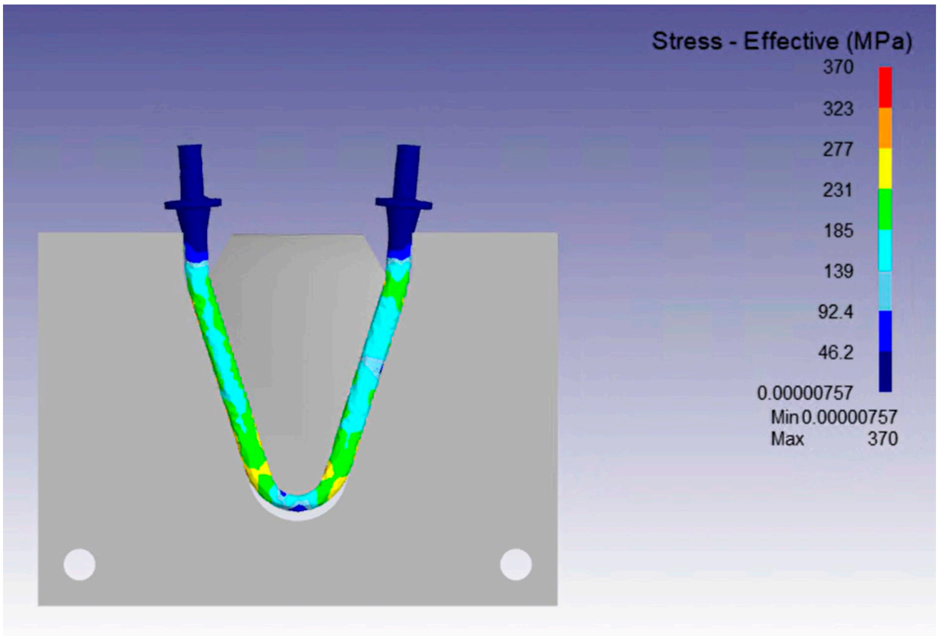


Figure 15. DEFORM simulations and experimental results measured by flange thickness at the same forging forces applied to the AISI 1018 steel workpiece at 600 °C in the bolt head forging operation with lubrication.

3.2.2. Bending Simulation and Experimental Comparison

Figure 16 shows an example FEA simulation and the resulting bent part. The final angles of threshing teeth have a consistent trend that as the force applied increases, the final angle slightly decreases, as evident in Figure 17. The final angle, measured as the inner angle of the workpiece after compression, changes very little at higher forces, which is explained by the forging that occurs at the end of the process. The final angle should be about 34° to 35° to adhere to the OEM part dimensions. The forging phenomenon is the same as that discussed in the tiller blade bending results in Section 3.1.2, and it contributes to the lower percent difference of 2.5% between the simulations and experimental results.



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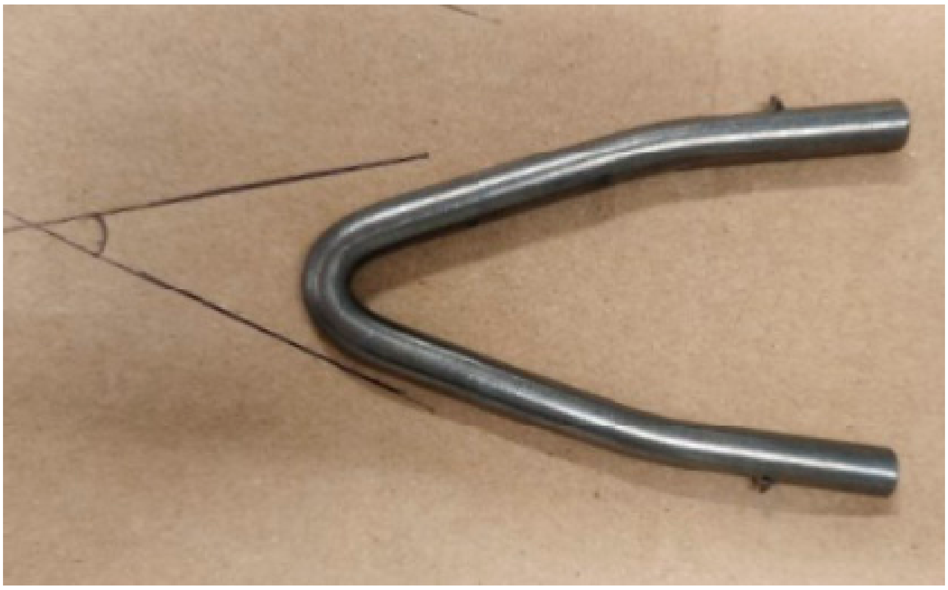


(**b**)

Figure 16. Bending the 6 mm diameter AISI 1018 steel threshing tooth at 20 °C. (**a**) FEA simulation effective von Mises stress. (**b**) Resulting bent part.

3.2.3. Flat Forging Simulation and Experimental Comparison

The final deformation process for threshing teeth is to forge the flats onto the bent portion of the tooth. Figure 18 shows a representative FEA simulation and the resulting part. The Wabash press only provides a maximum force of about 45 metric tons, and more tonnage is required to forge the cold workpieces to a thickness of 6 mm, so the resulting flat sections are thicker than required for the actual part. The agreement of the simulation and experimental results at lower force values, as shown in Figure 19, verifies the accuracy of the simulations at forging forces up to the required thickness of the flat sections at about 6 mm. The average difference is 1.4%. This very low deviation is due to the simplicity of the operation.

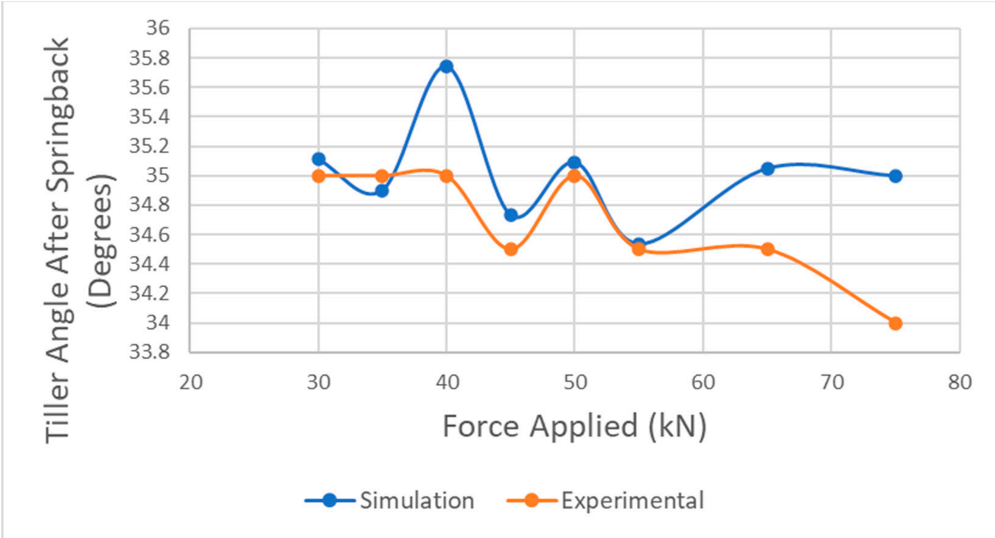
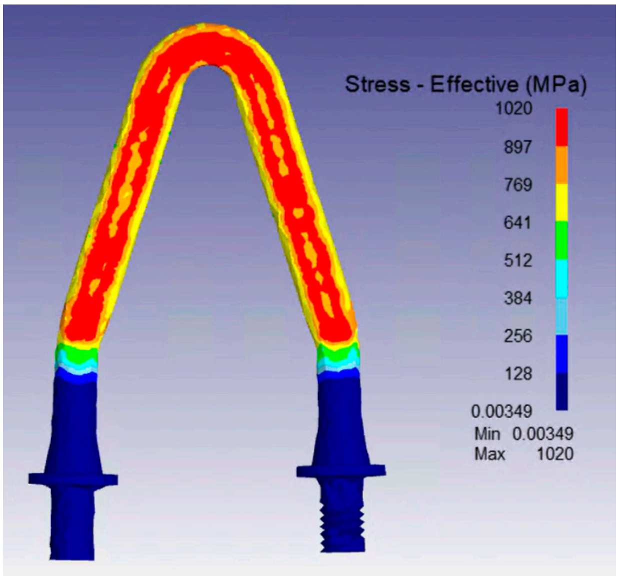
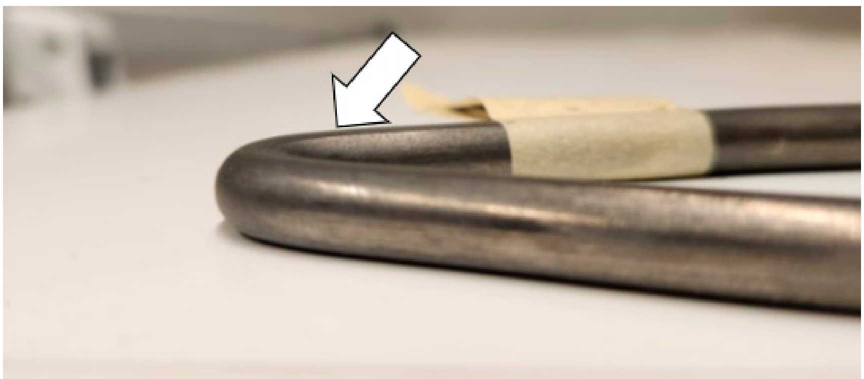


Figure 17. DEFORM simulation and experimental results for bending AISI 1018 steel threshing teeth workpieces at 20 °C with lubrication.



(**a**)



(**b**)

Figure 18. Forging flats onto bent 6 mm diameter AISI 1018 steel threshing teeth workpieces at 20 °C with lubrication. (**a**) DEFORM simulations effective von Mises stress. (**b**) Experimental results; white arrows designate flats.

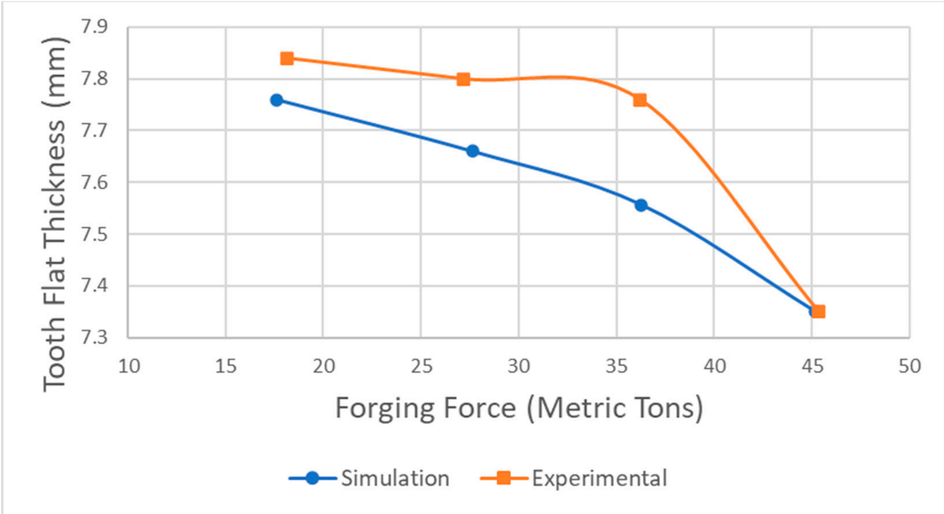


Figure 19. DEFORM simulations and experimental results for forging flats onto bent 6 mm diameter AISI 1018 steel threshing teeth workpieces at 20 °C with lubrication.

3.2.4. Threshing Teeth Manufacturing Recommendations

The recommended bolt head forging operation forces for the AISI 4140 steel workpiece at elevated temperatures are shown in Table 7. To avoid die failure and prevent the workpiece from seizing inside of the die, the workpiece should be heated to at least 600 °C before performing head forging. The bending operation recommendations are tabulated in Table 8. The bending operation should also be performed at elevated temperatures. The recommendations for forging the flats onto the bent tooth workpiece are shown in Table 9. This operation is simple due to its uncomplicated geometry, so the only recommendation is to perform this operation at elevated temperatures with lubrication to reduce required forces and die wear. All recommendations include a safety factor of 1.5, which can be modified as desired.

The recommendations presented in Tables 7–9 are feasible for SMEs in Bangladesh. As previously mentioned, furnaces are commonly used in current manufacturing facilities. Material availability, while slightly irregular in sourcing and uniformity, does support the manufacture of the threshing teeth. If material becomes available that greatly differs from the materials analyzed in this article, the same FEA simulation can be completed to determine the forces required to process it. Further, the proposed dies have been shown to be appropriate for manufacturing of these parts.

Table 7. Recommended processing conditions for bolt head forging the flanges on the AISI 4140 steel threshing teeth with lubrication.

Temperature (°C)	Force Required (kN)	Force Required w/SF of 1.5 (kN)	Die Stress (MPa)
600	158.7	238.1	2130
800	94.69	142.0	1250
1000	47.75	71.63	613.0

Table 8. Recommended processing conditions for bending the AISI 4140 steel threshing teeth with lubrication.

Temperature (°C)	Force Required (kN)	Force Required w/SF of 1.5 (kN)	Die Stress (MPa)
800	18.29	27.44	570.0
1000	8.600	12.90	360.0

Table 9. Recommended processing conditions for forging the flats on AISI 4140 steel threshing teeth with lubrication.

Temperature (°C)	Force Required (kN)	Force Required w/SF of 1.5 (kN)	Die Stress (MPa)
800	265.4	398.1	619.0
1000	145.3	218.0	320.0

4. Conclusions

This article details manufacturing processes, manufacturing dies, and their mechanical analyses for bending and forging operations able to generate two highly consumed, fast moving spare parts in Bangladeshi agricultural operations: the power tiller's tiller blades and the thresher's threshing teeth. First, die designs are generated to produce the required final geometry. The dies can be replicated in Bangladesh using existing commonly found machining equipment including CNC mills and lathes. FEA simulations of the manufacturing are performed at the elevated temperatures and die closure speeds and the materials available in Bangladesh to represent actual conditions. These simulations determined the forces involved, defined the size of equipment required, and showed that the dies will not fail. The FEA simulations were verified with physical experiments. Finally, processing conditions are recommended. The design and analysis method presented here provides a clear pathway to the design and manufacture of these two critical spare parts to support agricultural mechanization in Bangladesh. The method can readily be applied by engineers and manufacturers.

The manufacturing recommendations presented in this paper can be directly applied to SMEs in Bangladesh allowing them to select existing machinery or to purchase it. By following the recommendations, manufacturers will improve the quality and reduce the cost of manufacturing tiller blades and thresher teeth in Bangladesh, enabling the development of domestic manufacturing, increase of agricultural mechanization, and improvements in the balance of payments for the economy of Bangladesh.

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