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Design, analysis and manufacturing of flexible and functional stirrup and steel profile bundle-tie manufacturing machine

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ABSTRACT

Manufacturing process costs can be reduced by providing the mechanization of labor-intensive works such as construction and logistics operations in profile rolling. Although there are certain manual and semi-automatic machines available for the production of stirrups on constructions, using of physical strengths cannot be eliminated, and these machines cannot be used effectively for the production of steel profile bundle tie. In this study, it is aimed to design, analyze and manufacture of a functional machine based on hydraulic and automation system which has the flexibility to perform not only the production of bundle tie used in the transporting processes of the hot rolled steel profiles but also the stirrups used in construction sectors. The required process times for material feeding - straightening, bending, cutting and twisting operations were calculated. In line with the calculations, drive and transport mechanisms were designed and the motor-reducer pair was selected and the hydraulic cylinders and hydraulic power unit were dimensioned by using numerical engineering calculations. In order to validate the torque requirements of the motor-reducer groups which are calculated by using numerical engineering calculation methods, finite element method supported bending analyzes are performed and torque-time curves were obtained and the drive systems of the designed mechanisms are verified. Stress-time diagrams of Grade-75 rods, which are the raw material of bundle-tie production, are also obtained during the validation of the drive systems by finite element method supported analyzes. The bending regions of the bars were examined on the basis of the stress-strain diagram and the plastic forming capabilities of the process are evaluated. By this means, applying of excessive plastic deformation of the workpiece is prevented and optimizing of the final product's mechanical behavior is provided. By using the data obtained within the scope of the study, a flexible and functional structured machine was designed and manufactured which can perform many kinds of plastic deformation processes successfully.

Keywords— *Flexible manufacturing system, Straightening, Bending, Tying, FEA Analysis*

1. INTRODUCTION

Stirrups are closed structured reinforcement bars that hold the main reinforcement bars together in Reinforced Concrete Column structure as shown in Figure 1. In a column, stirrups provide lateral support to the main rods against buckling [1-3]. In the construction sector, the bending of the rods to obtain the stirrup from the rod material is generally carried out by hand or by using semi-automatically operated machines [1-11].

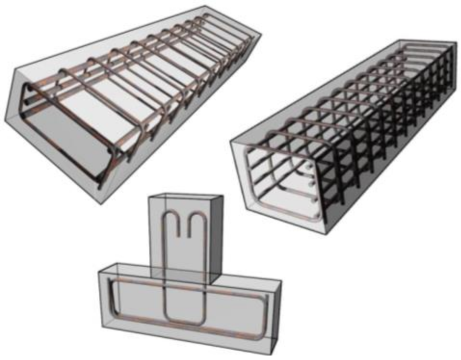

Fig. 1: Bended reinforcement bars

In the production of stirrups, steel bars which has smaller than 12 mm diameter are cut to length by shears of predetermined lengths and placed in bending devices [12]. Afterward workpieces are bent by using manual or semi-automatic bending machines and stacked manually as shown in Figure 2 [1,2,4]. In manual stirrup making systems, force is applied on the rod and the pin acts as a support to bend the rod. In manual bending process, in addition to the low efficiency of process, not only exposes the hands to repetitive movements but also causes muscular and skeletal system disorders as a result of high human energy expenditure [10].

Fig. 2: Examples of bending process (a) Manual bending process, (b) Semi-automatic bending machines

In the hot rolling industry, when the use of bent rods with stirrup-like geometry is examined; it is seen that bent rods (bundle tie) are used intensively in the logistics activities to transporting the bundled steel profiles are shown in Figure-3.

Fig. 3: Bundle ties used in hot rolling industry

As in the hot rolling industry, which requires the use of dense body strength, the production of transport equipment used in logistics operations is also carried out manually as shown in Figure 4.

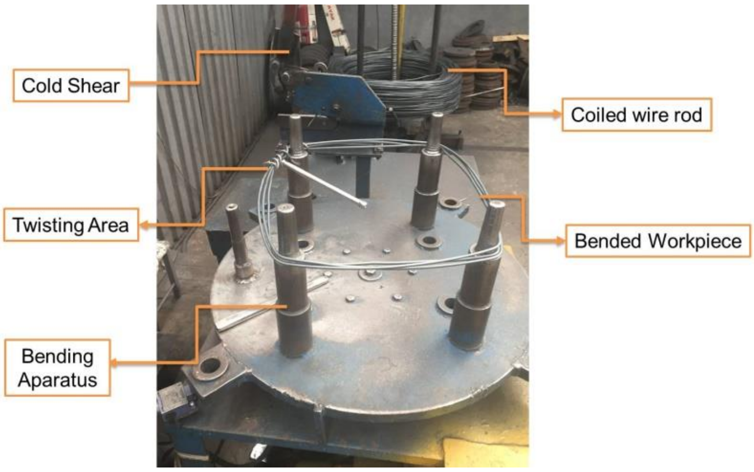

Fig. 4: Bundle tie forming fixture

Coiled wire rods are used as a workpiece which diameter is 6 millimeters on bundle tie production. The coiled wire rod placed in the feeder is passed between the guillotine shear blades manually. The workpiece is rotated for 3 turns so as to overlap around the suitable apparatus for the predetermined bundle tie and bending process is done. After the bending work is completed, the workpiece is cut at the end of the length. Remained part at the end of the length is tied around the 3 times overlapped bended part and the bundle tie production is completed. In addition to the low production efficiency resulting from hand-work and production of bundle ties, dimensional deviations may occur in bundle ties. Intensive body strength usage and repeated physical actions constitute the risk of occupational accidents and occupational diseases.

When the literature is examined regarding the design and production of the machinery and wire forming machines used in various fields of industry; Anbumeenakshi et al. designed a mechanical powered hydraulic bending machine that can produce multiple stirrups at the same time. The stirrup making machine with hydraulic systems is easy to use. Different types of stirrups can be produced by using fixtures with different dimensions and geometries. This machine is capable of producing 20 pieces of stirrups in 15 minutes but the workpiece must first be cut to the desired length and positioned manually [2]. Thokale et al. Aimed to implement the pneumatic rod bending machine in the construction sites with less cost compared to the existing bending machines and increasing the productivity of the stirrups. Pneumatic rod-bending machines consist of Pneumatic equipment. The rod is bent by the Pneumatic cylinder with holding the rod in the fixture. The main advantage of this design is the square shape of the stirrups is bent continuously without repositioning the rod in the machine [13]. At the design study of Gujar et al. The reciprocating motion of pneumatic cylinder is converted into rotary motion by using Scotch Yoke Mechanism. When the motor feeds the rod, the first limit switch is activated. The limit switch gets pressed by the feeding rod over it and a signal is sent which stops the motor quickly and direction control valve gets actuated, which operates pneumatic cylinder and the Scotch yoke mechanism. Rod is bent by the piston stroke. Afterward the rod is fed until it reaches the second limit switch and the signal is sent to the controller. Finally, third limit switch again realizes same procedure till stirrup forming is completed [5]. Waghmare et al. aimed to improve the stirrup making efficiency and production capacity of stirrup by using human powered flywheel motor of stirrup making. A system similar to a bicycle having flywheel is conceptualized as Human Powered Flywheel Motor (HPFM) in which a human being spins a flywheel at about 600 RPM to store energy. After then stored energy is used in stirrup making process and stirrup production is realized [9]. Vadaliya Darshit et al. aimed to design and construct a machine that has high production rate with less man power and desired accuracy.

Bar bending machine is consist of electric motor and powertrain components. Electric motor transmits power which is used to bend bar with the help of circular plate. Bend at any required angle for bar having diameter 6 to 16mm [6]. When reviewing all of the relevant literatures, there are a lot of stirrup making machines work on pneumatic and hydraulic systems or semi-manual systems but there is no machine design that has the flexibility to perform both bundle tie production and stirrup production completely automatically.

In this study; flexible and functional machine that performs straightening and feeding, bending, cutting, fixing and tying operations completely automatically has been designed, numerically calculated, finite elements method based analyzed and manufactured to produce both the stirrups used in the construction industry and the bundle ties used in the logistic operations like loading and unloading of steel profile bundles in the hot rolling industry.

2. MATERIAL AND METHODS

2.1 Material

The scope of this study; the rebar used as the raw material of the stirrups used in the production of Reinforced Concrete Column in the construction industry and the coiled wire rods used in bundle tie manufacturing were used. Mechanical properties and chemical compositions of raw materials to be formed, which is the first factor determining the machine capacity in machine design studies, are shown in Table 1 [14,15].

Table 1: Mechanical properties and Chemical compositions of raw materials

Standard	Grade	Chemical Composition Wt%					Mechanical Properties		
		C	Mn	Si	P	S	Rp (MPa)	Rm (MPa)	Elongation %
A615/A615M-09b	Grade 75	-	-	-	0,06	-	520	690	7
AISI 1010	1010	0.1	0.6	0.2	0.03	0.03	305	365	20

2.2 Methods

In the scope of machine design work, the materials shown in table 1 are taken as reference. It is aimed at the sub-systems of the machine have demountable features because of the design of a concept machine that has the flexibility to realize both the stirrup and bundle tie production during the design phase. The operation flowchart of the machine is shown in figure 5.

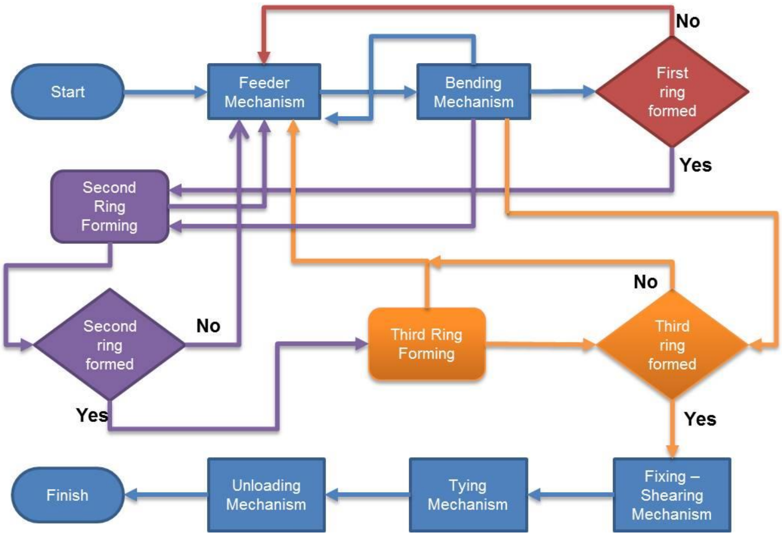

Fig. 5: Process flow diagram

The systematic of the mechanisms used in the flow diagram mentioned in figure 5 are below mentioned:

The workpiece is straightened by the pressing forces applied by the straightening mechanism which is driven by the electric motor-reducer group. The workpiece is fed to the bending mechanism according to the dimension to be bent. The bending mechanism which performs bending with the torque provided from the motor-reducer group is moved to the upward position by using hydraulic cylinder and performs the bending operation. This process is repeated with reference to the geometry to be formed. After the bending process is completed, the hydraulic cylinder which moves up and down to the bending mechanism is energized and it is provided to come to downward position. When the bending stage of the workpiece is completed; workpiece is positioned at the center of the tying mechanism and the workpiece is fixed by hydraulic fixtures at the inlet and outlet of the tying mechanism. Then the bundle-tie is cut at the end of the length by moving upward position of the hydraulic knife. After the hydraulic knife comes to bottom position; the twisting mechanism is locked by the hydraulic cylinder in the twisting mechanism is in the forward position. The motor-reducer group is energized and twisting process is completed by rotating around workpiece's own axis. Cycle time calculation was done for the bundle tie production process used in the hot rolling industry and the cycle time calculated for bundle tie production was determined as 57 seconds.

2.2.1 Subsystems Design and Numerical Calculation Studies

(a) Straightening – Feeding Mechanism: At this design stage; the straightening-feeding mechanism was planned to be used only in 6 mm diameter workpiece's straightening process. So, the motor power requirement of the straightening-feeding mechanism is calculated according to the equations 1-7 as it is planned to be straightened by applying 1 mm displacement to the workpiece.

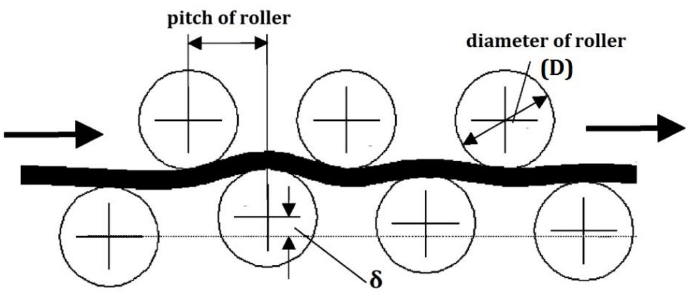

Fig. 6: Straightening– Feeding schematic [16]

V = R x w	(1)
δ = (F x L3)/ (48 x E x I)	(2)
P = T x w	(3)
R= D/2 = 0.044 m	(4)
δ=1 mm=0.001m	(5)
I = (π x d4)/64 so IØ6mm=63.6 x 10-12 m^4	(6)
E=210 GPa=2.1 x1011 N/m^2	(7)

According to the above-mentioned calculations V is linear velocity of rollers (m/sec), R is radius of rollers (m), L is length between supports (m), E is elasticity modulus (GPa), I is moment of inertia of workpiece (m4), δ is maximum deflection at center (m), P is motor power (Watt), T is torque requirement (Nm) and w is angular velocity (rad/sec). The feed rate of the designed straightening-feeding mechanism is 0.26 m/sec. Therefore, the angular velocity of the straightening rollers is calculated as 5.9 rad/sec. According to the magnitude of the maximum displacement planned at the center, the pressing force is 641 N and the feeding force is 448.7 N. Since the bottom rollers of the mechanism are driven and the upper rollers are idlers, the required motor force is calculated as 0.93 kW and motor power was selected 1.1 kW. The CAD model of the straightening-feeding mechanism is shown in figure 7.

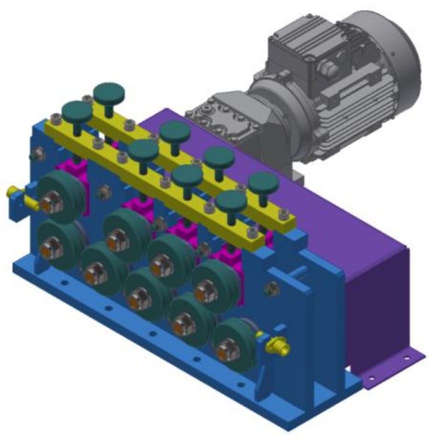

Fig. 7: CAD model of the straightening- Feeding mechanism

(b) Bending Mechanism: Functional bending mechanism is powered by a central hydraulic unit, where the electrical power supply makes the electric motor to run and the hydraulic power unit provides the necessary force that is required upward movement to bending mechanism before bending the rods. After upward movement of bending mechanism to wire rod, electric motor-gearbox group is powered. When the motor is energized, the turning moment is transferred to the gear group so that the bending mechanism is rotated and the workpiece is bent. After the bending stage is completed, the double-acting hydraulic cylinder moves downward to return the bending mechanism to its starting position. Capacity of the bending mechanism is designed to bend 2 pieces of 6 mm diameter wire rods or 1 piece 12 mm diameter ribbed bar at the same time. Schematic of the bending mechanism is shown in figure 8.

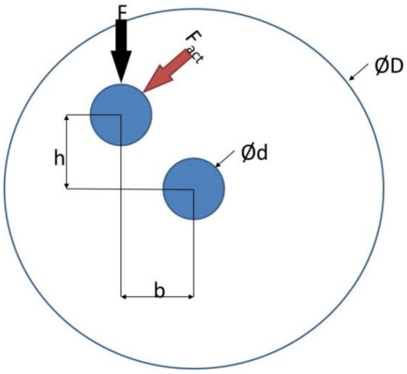

Fig. 8: Bending mechanism

$$\sigma_b = My/I \quad (8)$$
$$M = F \times b \quad (9)$$
$$F = F_{act} \times \cos\Theta \quad (10)$$
$$T_1/D_1 = T_2/D_2 \quad (11)$$
$$P = (2 \times \pi \times n \times T)/60 \quad (12)$$

According to the above-mentioned calculations σ_b is bending stress (MPa), y is perpendicular distance to neutral axis (mm), M is moment about neutral axis (Nmm), P is motor power (Watt), T is required torque for bending motor (Nm) and n is number of revolution (rev/min). In order to bend the one piece of Grade-75 material with a diameter of 12 mm or two-wire rods with AISI 1010 material with a diameter of 6 mm in the specified geometries, the required motor power is calculated according to the equations 8-12. The required motor power was found as 0.75 kW [1,5,6]. In line with the calculated bending process cycle time, reducer selection is done and gear ratio of the reducer is 114.14 and provided torque of the system is 533 Nm.

(c) Fixing-Shearing Mechanism: Fixing and shearing of the workpiece is planned to obtain by using hydraulic cylinders. At the beginning of the shearing process, the moving shear blade moves toward the bar, which causes elastic and plastic deformation of the bar material. Then, fixing plate and shearing blade penetrate the workpiece and create smooth cut surfaces on the front ends of the workpiece. Plastic deformation occurs in an increasingly until the deformability limit of the material is exceeded. The continuous enlargement with an involved increasing notch effect induces microscopic cracks, finally forming an aligned fraction line between the two cutting areas. The workpiece is separated from the remaining piece [17].

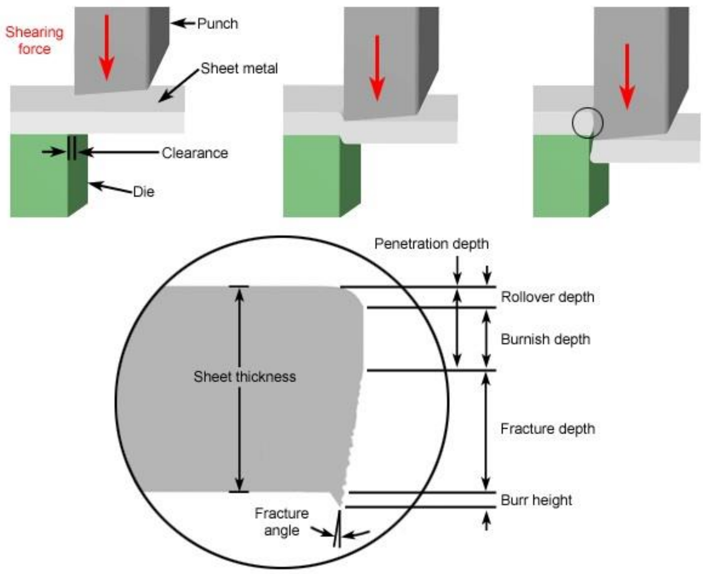

Fig. 9: Shearing methodology [18]

Required force for shearing was calculated according to shearing of billet calculation.

$$Fs = A_s \times k_s \quad (13)$$

Where A_S is the cross-sectional area of the billet and k_S is the material-specific shear resistance, resulting from the tensile strength of the material:

$$ks = 0.7\ldots 0.8 \times R_m \quad (14)$$

From equations 13 and 14, the force required to cut the coiled wire rod which has 6 mm diameter was found as 7220 N [17].

Hydraulic System Calculations:
The shearing mechanism is cut the workpiece by shear which is powered by hydraulic cylinder. So, required cylinder dimensions in order to perform cutting work can be calculated from equation 15.

$$\sigma = F/A_{cylinder} \quad (15)$$

Since the planned hydraulic pressure will be 150 bar, the cylinder selections were made according to equation 3 with reference to the planned process times as shown in Table-2 [19].

Table 2: Selection of hydraulic cylinders

Cylinder Name	Cylinder Forward Speed (cm/sec)	Cylinder Diameters (mm)
Fixing	5 cm/sec	Ø32xØ18
Shearing	5 cm/sec	Ø32xØ18
Bending Mechanism Upwards-Downwards	5 cm/sec	Ø32xØ18
Tying Mechanism Fixing	2.5 cm/sec	Ø40xØ22

(d) Tying Mechanism: In the context of the designed tying mechanism; after the bending process has been completed, three times the overlapped ring-shaped workpiece is positioned to the center of the gear mechanism which major diameter of sprocket 208 mm. When the double-acting hydraulic cylinder is moving to forward position, the overlapped area at the workpiece in the gear center is locked. After locking the gear mechanism, the motor-gearbox group is energized and the workpiece is tied by rotating the overlapped area of the workpiece along the axis. Solid model of designed mechanism is shown in figure 10.

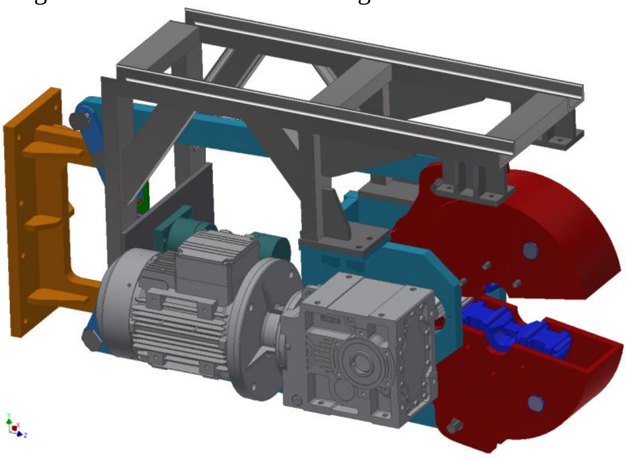

Fig. 10: CAD model of the tying mechanism

Motor power calculation for maximum 12 mm diametered rebar tying process:

$$I = (\pi x d^4)/64 = (\pi x 124)/64 = 1{,}017.36 \text{ mm}^4$$

$$y = 6 \text{ mm}$$

$$\sigma b = (M \text{ x } y)/I \rightarrow 630 = (M \text{ x } 6)/1{,}017.36 \rightarrow M = 106{,}822{,}8 \text{ Nmm}$$

Because of the rebar is overlapped for three times:

$$M_{Total} = Mx3 = 106{,}822.8 \text{ x } 3 = 320{,}468.4 \text{ Nmm}$$

Required motor power is determined as shown in equation 12 by using the obtained data according to calculations 1-11 [1,5,6].

$$P = (2 \text{ x } \pi \text{ x } n \text{ x } T)/60 = (2 \text{ x } \pi \text{ x } 56 \text{ x } 320.46)/60 \rightarrow P = 1.8 \text{ kW}$$

Motor power is selected as 2,2 kW as the standard motor which provides the required motor power.

2.2.2 Validating of design by using Finite Elements Analysis
Within the scope of numerical engineering calculation studies carried out in the previous sections, validating of the torque requirement of the selected bending mechanism is aimed. For this purpose, the selection of the motor power of the designed bending mechanism is validated by static analyzes supported by the finite element method by using ANSYS software as shown in figure 11.

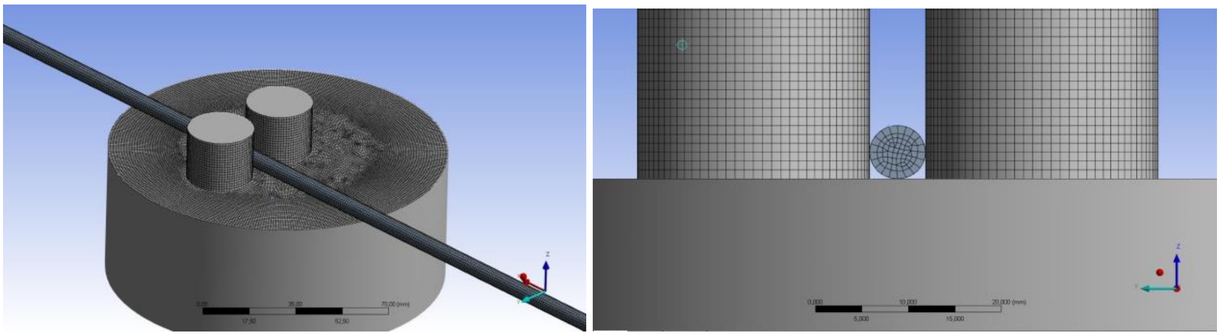

Fig. 11: CAD model of the tying mechanism

During the Finite Elements Method aided analysis of the bending mechanism, parameters that are used in the analysis are shown in Table 3. At the analysis, bending mechanism's fixture material behavior was selected as rigid for shortening the analysis period. Workpiece which would be bended was selected as Grade-75 and the workpiece's diameter was selected as 6 mm.

Table 3: Finite Elements Method aided analysis's parameters

Analysis Type	Static Structural
Material Type of the Bending Mechanism	Rigid
Material Type of the Workpiece	Grade 75
The diameter of the Workpiece	6 mm
Mesh Type	Hexahedral
Mesh Size	Orthogonal Quality (Max. 1mm, Min. 0.6mm)
Element Count	114405

3. RESULTS AND DISCUSSIONS

3.1 Finite Elements Method Aided Bending Mechanism's Analysis Results

As can be seen from the analysis outputs in figure 12, it is seen that the yield strength of the Grade-75 workpiece material is exceeded during the bending process. Therefore, it is seen that plastic forming is performed successfully. When the bending area of the workpiece is examined in detail, it is seen that the magnitude of the tensile stresses occurring during the deformation is greater than the compressive stresses.

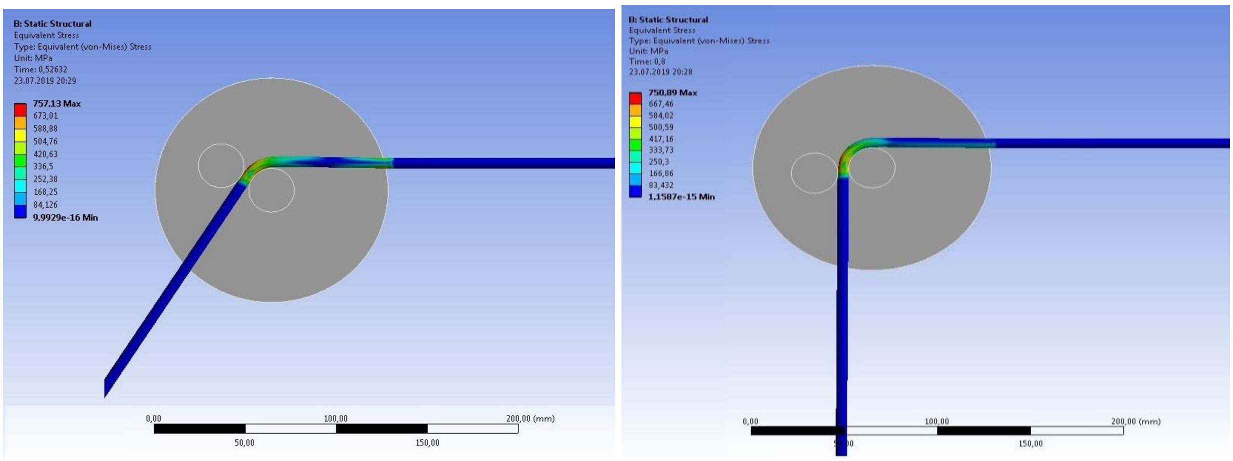

Fig. 12: Stress distribution of workpiece's bending zone during bending

At the end of the bending process, the distribution of residual stresses in the bending region of the workpiece was determined that varies from 400 MPa to 700 MPa as shown in figure 13. It is seen that the workpiece was deformed and retained the shape in accordance with the residual stresses which was applied effectively.

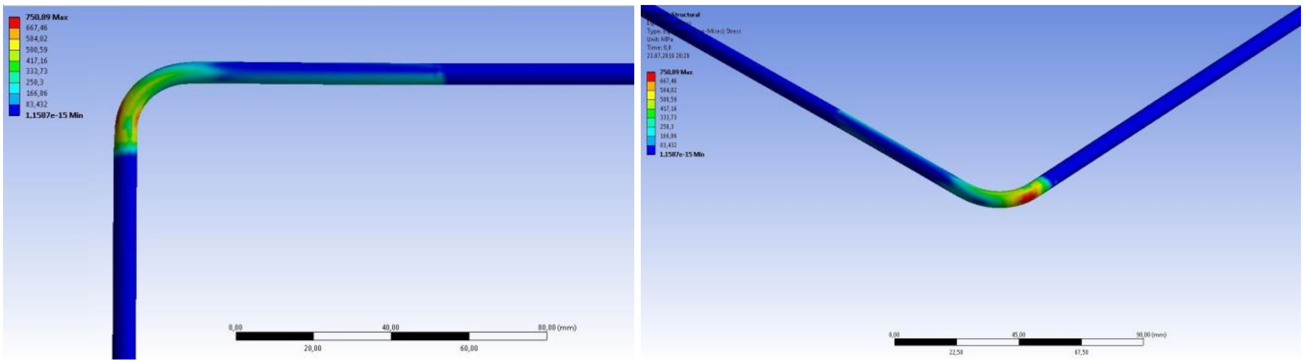

Fig. 13: Stress distribution of workpiece's bending zone after bending

The time-dependent variation of the stress distribution in the workpiece during the bending process is shown in figure 14. As can be seen from the Stress-Time curve, plastic stress was generated over the yield strength of the workpiece (520 MPa) during the bending process. In this way, it was determined that an effective plastic forming process was applied.

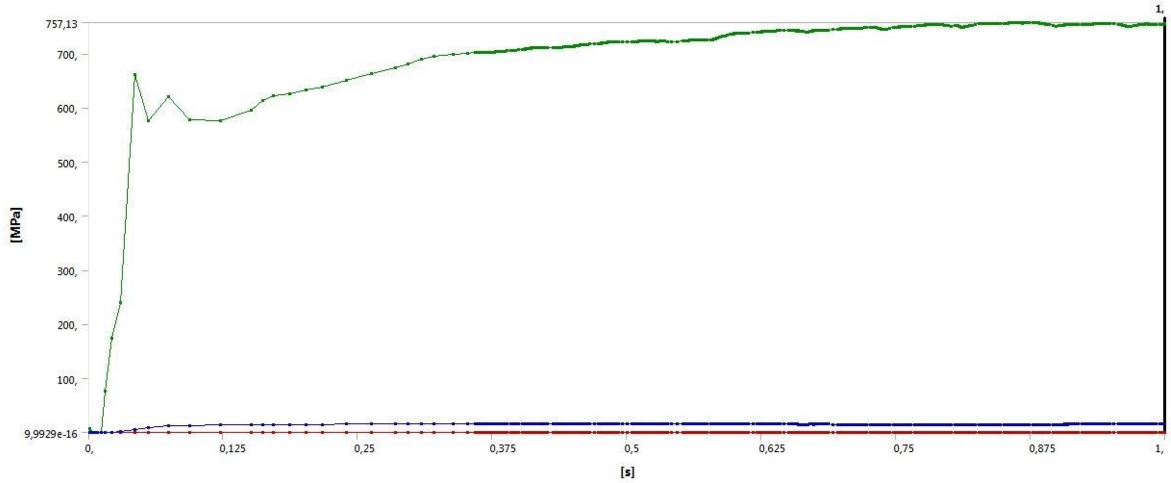

Fig. 14: Stress - Time curves of workpiece obtained from the bending process

According to the Torque-Time diagram obtained as a result of Finite Element Assisted Bending Analysis of Bending Mechanism as shown in figure 15, it is seen that 124.8 Nm torque requirement is needed to bend 6mm diameter workpiece with Grade 75 material. Considering the torque (533 Nm) provided by the motor-reducer system selected as a result of numerical engineering calculations, it is seen that three pieces of 6 mm rods with Grade-75 materials can be shaped simultaneously. Therefore, it was determined that the torque requirement obtained as a result of bending analysis supported by the finite element method and motor-gearbox selection chosen as a result of numerical engineering calculations overlap with each other to a great extent.

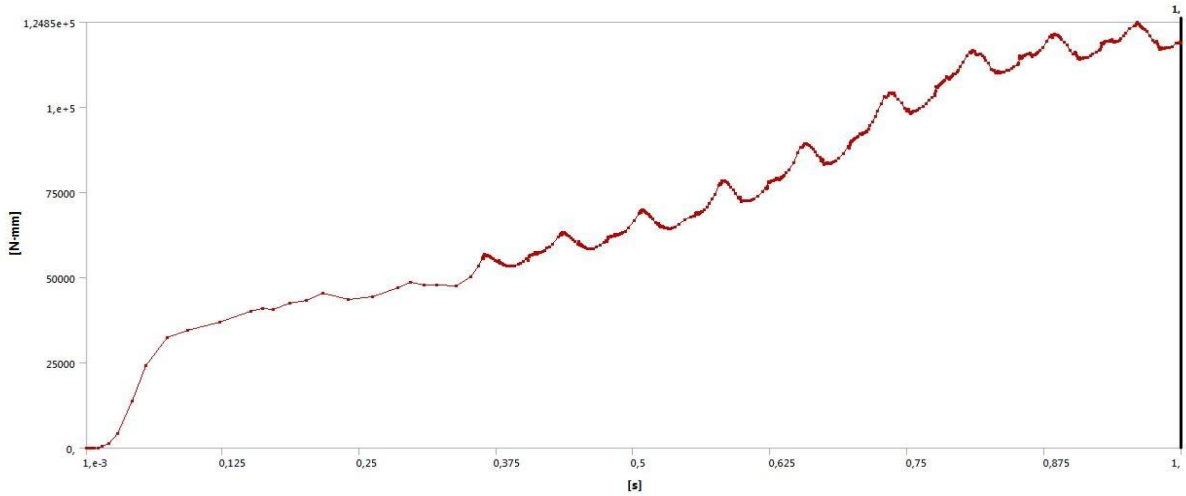

Fig. 15: Torque requirement depending on time of binding mechanism

At the end of the numerical engineering calculation, finite elements method aided analysis studies, the machine chassis, components, and mechanisms have been sized. The solid model of the machine is shown in the Figure-16.

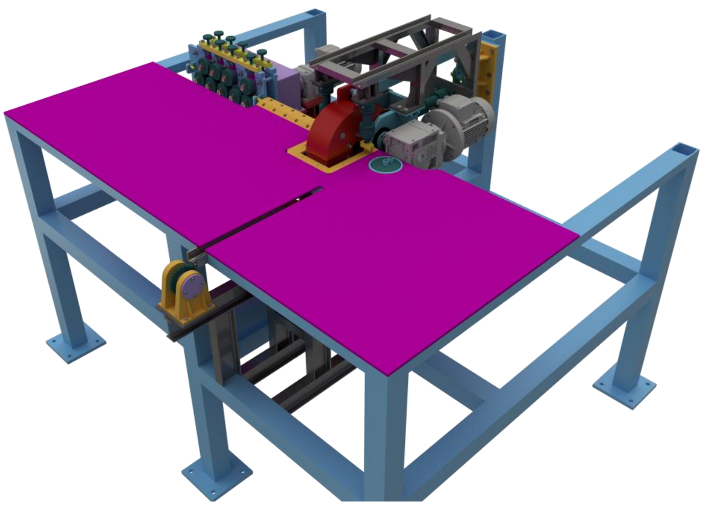

Fig. 16: CAD model of the bundle-tie forming machine

3.2 Manufacturing Studies of Machine and Prototype Productions of Bundle Ties

The selection of materials to be used in the chassis and mechanisms is made, welded fabrications and machining operations have been completed. Examples of welded fabrications, machining and assembling operations are shown in figure 17 and figure 18.

Fig. 17: Welded fabrications of the chassis

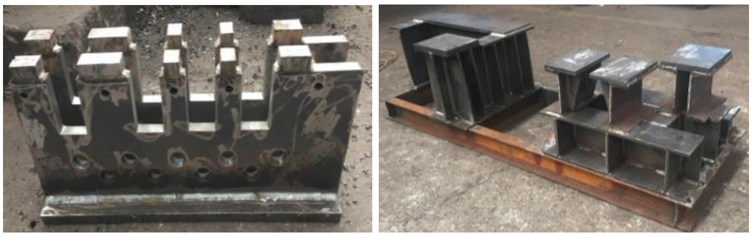

Fig. 18: Machined structures of the straightening-feeding mechanism

At the end of the assembling stage, the automation system was designed and integrated into the prototype machine as shown in figure 19. By using this automation interface, cycle times and feeding ratios can be adjusted and different shaped stirrups and bundle ties can be manufactured.

Fig. 19: Assembling studies of the bundle-tie manufacturing machine

When the machine was implemented, cycle-time studies were made and capacity calculation and cycle times were calculated. The capacity data were obtained as a result of bundle-tie production is shown in Table 4.

Table 4: Bundle-tie production capacity of the designed machine

Coiled Wire Rod Total Length	10810	Meters
Bundle Tie Total Length	8	Meters/Tie
Total Bundle Tie Production	1348	Pieces/Coil
Number of Bundle Tie Production	466	Pieces/Shift

The raw material dimensional properties of the products were obtained that can be produced by using the driven mechanisms selected during the phase of machine design studies and the formability limits of the mechanisms are shown in Table 5.

Table 5: Formability capacities of a designed machine

Mechanism	**Workpiece Forming Capacity Values**			
	Stirrup		**Bundle Tie**	
	Max. Diameter	**Quantity**	**Max. Diameter**	**Quantity**
Straightening - Feeding	Ø6 mm	1	Ø6 mm	1
Bending	Ø12 mm	1	Ø12 mm	1
	Ø6 mm	2	Ø6 mm	2
Shearing	Ø6 mm	1	Ø6 mm	1
Tying	Ø12 mm	3	Ø12 mm	5
	Ø6 mm	6	Ø6 mm	9

At the end of the manufacturing and assembling of the machine, prototype productions of steel bundle ties were realized as shown in figure 20.

Fig. 20: Test studies of Straightening – Feeding and Bending Mechanism

4. CONCLUSION

- An innovative solution for stirrup and bundle tie production is obtained by using both numerical engineering calculations and Finite Elements Method aided analysis and optimizations at the design phase of the machine.
- It is seen that the data obtained as a result of the Finite Elements Method based analyzes carried out for the bending mechanism largely match up with the torque requirements of the motor-reducer pair chosen as a result of numerical engineering calculations.
- Similarly, it has been determined that by optimizing the plastic forming process in accordance with the stress-strain and stress-time data obtained within the scope of finite element method supported analyzes and residual stress formation can be characterized and an effective deformation process can be designed to increase the final product quality.
- The production capacity of the machine is around 450 bundle-tie which has 8 meters unfolded length in 7 hours of effective working per day. The production capacity of the machine for stirrup production of 600x250 mm of sizes; more than 4 times of bundle-tie production.
- In order to produce products with different geometries by using workpieces that have circular cross-section, the forming machine has been designed and manufactured which can perform several plastic forming operations like straightening, bending, shearing and tying.
- Without using any fixtures in the machine, different shapes and sizes of the stirrups or bundle-ties can be achieved thanks to setting the feeding time of the straightening-feeding mechanism and turning angle of bending mechanism.
- Since all the mechanisms on the machine are demountable, some of the mechanisms can be disabled or the mechanisms with larger capacity can be replaced. This is another factor that gives the machine a flexible manufacturing capability.
- When different designs related to this type of machines are examined in the literature, it is seen that the design obtained in this study gives a different and innovative perspective to the designs in the literature [1-11].
- Because the machine can meet different plastic forming methods, the product with the desired geometry without any operator intervention and without effort can be produced and stacked automatically.
- At the design stage of the machine; Since the positioning of all systems that will drive the mechanisms within the machine chassis gives the machine the ability to be easily transported, it allows the machine to be transported within the factories with the transportation vehicles such as crane and forklift without the need for any assembling-disassembling process.

5. REFERENCES

[1] P. N. Awachat, G. Dastgeer, A. Gohite, Design and analysis of re-bar bending machine. International Journal of Innovative Research in Advanced Engineering (IJIRAE) Issue 4, Volume 2 (2015), 103-105. ISSN: 2349-2163.

[2] C. Anbumeenakshi, M. R. Thansekhar, M. Thanamani, R. Santhoshkumar, S. Parivalla, K. Senthilkumar, Design and fabrication of multirod bending machine, International Journal of Current Engineering and Scientific Research (IJCESR), Volume 5, Issue 1 (2018), 20-24.

[3] A. V. Vanalkar, P. M. Padole, Optimal design of mechanism for stirrup making machine – A Computer approach, 11th National Conference on Machines and Mechanisms (NaCoMM 2003).

[4] V. Shinde, D. Adhav, S. Jadhav, A. Attar, S. Gorde, Design and fabrication of hydraulic stirrups making machine, International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), Volume 5, Issue 5 (2016), 8362- 8366.

[5] A. N. Gujar, T. D. Kadam, V. V. Shinde, G. E. Chavan, A. J. Mane, Design and development of pneumatic stirrup bending machine, International Journal of Advance Engineering and Research Development, Volume 4, Issue 3 (2017), 479-485.

[6] V. Darshit, T. Kuldip, V. Bhargav, U. Mohmmadaamir, T. Kishan, N. Gevariya, Design and analysis of bar-bending machine, International Research Journal of Engineering and Technology (IRJET), Volume 5, Issue 4 (2018), 172-175.

[7] S. J. Mahendra, O. S. Chilmulwar, S. S. Kuntawar, U. S. Mirza, D. V. Bhope, Review paper on stirrup making machine, International Research Journal of Engineering and Technology (IRJET), Volume 5, Issue 3 (2018), 2112-2119.

[8] M. Virani, J. Vekariya, S. Sheth, K. Tamboli, Design and development of automatic stirrup bending mechanism, Proceedings of the 1st International and 16th National Conference on Machines and Mechanisms (iNaCoMM 2013), IIT Roorkee, India, Dec 18-20 2013, 598-606.

[9] S. N. Waghmare, C. N. Sakhale, M. P. Singh, Design, development and fabrication of stirrup making machine energized by human powered flywheel motor, International Conference on Multidisciplinary Research & Practice, Volume 1, Issue 8 (2014), 532-536.
[10] S. N. Waghmare, C. N. Sakhale, Formulation of mathematical models for establishing processing time of stirrup making operation using human powered flywheel motor, International Journal of Application or Innovation in Engineering & Management, Volume 4, Issue 6 (2015), 176-189.
[11] O. S. Chilmulwar, S. J. Mahendra, N. N. Kodurwar, J. C. Piprode, D. V. Bhope, Design and fabrication of pneumatic stirrup making machine, International Research Journal of Engineering and Technology (IRJET), Volume 5, Issue 3 (2018), 2091-2094.
[12] S. N. Waghmare, C. N. Sakhale, Design of experiment for formulation of experimental data based model for stirrup making operation using HPFM, International Journal of Scientific Engineering and Applied Science (IJSEAS), Volume 1, Issue 4 (2015), 341-347.
[13] T. Manoj, K. Satish, K. Rahul, M. Suyog, P. Mahesh, Design and fabrication of pneumatic bar bending machine, International Research Journal of Engineering and Technology (IRJET), Volume 4, Issue 3 (2017), 1403-1406.
[14] P. D. Harvey. Engineering properties of steel. Metals Park, OH: American Society for Metals, 1982.
[15] ASTM, SASO. Standard specification for deformed and plain carbon-steel bars for concrete reinforcement. 2009.
[16] B. Biju, J. S. Dijin, C. Anujith, A. Augustine, A. P. Mohammad, Design and analysis of straightening mechanism for commerical steel bars, International Research Journal of Engineering and Technology (IRJET), Volume 3, Issue 5 (2016), 379-383.
[17] BA. Behrens, Billet shearing, In: C.I.R.P., Laperrière L., Reinhart G. (eds) CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg, 2014, 1-5.
[18] K. Barman, N. Ali, R. Hasnat, S. M. H. Kabir, Fabrication of a pneumatic sheet metal cutting machine, Proceedings of the International Conference on Mechanical Engineering and Renewable Energy 2017 (ICMERE2017), 2017.
[19] P. J. Chapple, Principles of hydraulic systems design, first ed., Coxmoor publishing company, 2003.

