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Investigation of Effects of Using Caliber Rollers in VSB Edger of Roughing Mill of Mobarakeh Steel Company

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Abstract: *One of the slab width reduction methods in hot rolling mill is to use vertical rollers called edger; this is called the edging process. In edging process the slab thickness near the edges of the workpiece which are in contact with edger rollers is more than the other parts which results in apparent rise in the edges of the workpiece called dog bone. This uneven thickness increment decreases efficiency of the edging process. One of the methods to avoid or decrease dog bone is to use caliber rollers in width reduction process. Experimental results obtained from hot rolling manufacturer show that in case of proper choosing of the caliber rollers, efficiency of edging process increases from 30% to about 70%. In this research, effects of using caliber rollers in Mobarakeh Steel Company roughing mill VSB edger are studied by using a commercial software. Based on the results of this research, it has been recommended to change the roller type from flat to caliber. According to this study, using caliber rollers will result in reduction of dog bone, improvement of edging efficiency and enhancement of stability of the edging process..*

Keywords: *Mobarakeh Steel Company, edging process, caliber rollers, slab deformation.*

I. Introduction

One of the important quality parameters of hot rolling products is the product's width. In the process of developing width control systems in hot rolling factories, three main purposes are followed:

1. Supplying products' compact width tolerances according to customer order
2. Increasing the magnitude of slab and bar width reduction in order to reduce number of slabs with different width
3. Reducing losses due to non-uniform deformation of high widths reduction

In steel producing factories which use continuous casting to produce slabs, the variations of slabs width are limited. So, in order to produce products with diverse widths from slabs of limited width variation, a rough rolling process in which the slab's dimensions (width and thickness) get changed in several rolling processes is needed, which is frequently done in a reciprocating manner, to obtain suitable dimensions needed for final rolling process. Figure 1 shows the schematic of roughing rolling unit of hot rolling Mobarakeh Steel Company.

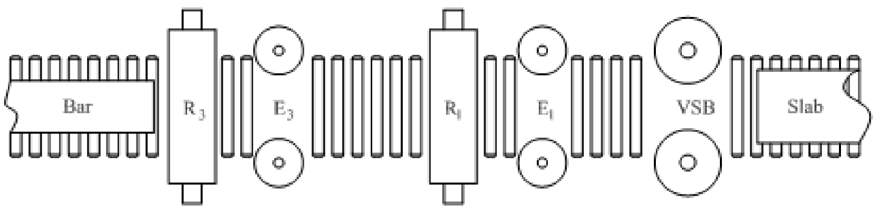


Fig. 1: Schematic of roughing rolling unit of Mobarakeh Steel Company

The most frequent methods of changing width in hot rolling factories are:

- ❑ Width reduction by rolling
- ❑ Width reduction by pressing
- ❑ Longitudinal cutting

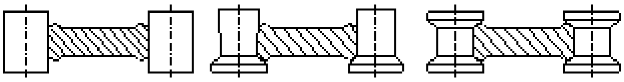
Only the first method is used in Mobarakeh Steel Company.

II. Width Reduction by Rolling

The process of reducing workpiece width is called edging. Edging can be done by either rolling or pressing. Three kinds of rollers are usually used in edging by rolling (Fig. 2):

a) Flat Cylindrical Rollers
b) Tapered Rollers
c) Caliber or Grooved Rollers

In this study cases ‘a’ and ‘c’ are studied.



a) b) c)

Fig. 2: Frequently used rollers in edging process

Thickness increment of bar edges in edging process is called dog-bone shape which is shown in figure 3. In the process of bar rolling, while the bar thickness decreases, the length and width of which increase. The bar width increment which is due to thickness reduction is called lateral spread.

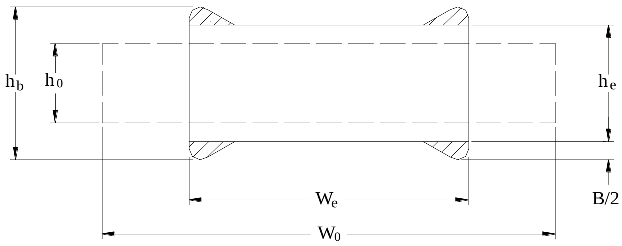


Fig. 3: Thickness increment of bar edges

Moreover, when the output bar from edger has been rolled by horizontal shelve and reduced thickness, there is an additional bar width increment due to rolling of bulgy edges which is called recovery dog-bone. This width increment is because of two fundamental factors (Fig. 4):

1. Width increment due to bar edges thickness reduction (recovery dog-bone)
2. Width increment due to bar body thickness reduction (lateral spread)

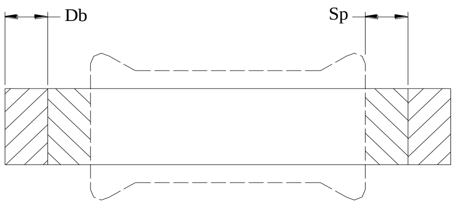


Fig. 4: Width increment due to bar edges thickness reduction and bar body thickness reduction

2.1 Edging process using flat cylindrical rollers

The bulgy profile of bar edges in edging process depends on types of rollers used. The amount of bulging in edges is more when flat cylindrical rollers are used. The maximum bulging height in edges is:

$$B = h_b - h_0 \quad (1)$$

where h_b is bar thickness at the point of maximum bulging and h_0 is bar thickness before edging process. A number of researchers like Wusatowski [1], Shibahara *et al.* [2], El-Kalay and Sparling [3], Okado [4], and Helmi and alexander [5] have proposed experimental relations for calculating maximum bulging height of bar edges in edging process using flat cylindrical rollers.

2.2 Edging process using caliber rollers

One of the basic questions in edging process is whether to use flat rollers or caliber ones. Flat rollers are usually used when width reduction of slabs and bars with different thickness have to be done by one edger. Using flat rollers results in reduction of both rolling force and required torque. In addition, using these rollers in edging process increase the rollers’ life.

However, when high widths reduction ratios needed, using flat rollers causes instability in edging process.

Using caliber rollers makes it possible to achieve below purposes:

- Stability enhancement of edging process
- Increasing the amount of width reduction in one pass
- Increasing the amount of effective width reduction

Increasing the amount of effective width reduction by using caliber rollers in edging process is often due to this fact that these rollers shift the apex of bulging in edges to the center of the slab; so in thickness reduction process, the amount of width increment due to recovery dog-bone is minimized. This fact has also been approved by practical rolling results.

III. Finite Element Analysis of Width Reduction Process

Since designing and making tools needed in metal forming processes requires excessive time and cost consumption, using numerical solutions makes it possible to study the effective parameters in designing accurately before making the prototype and is capable of reducing probable costs due to future changes in design dramatically.

In this study, hot rolling width reduction process has been simulated and studied by a commercial finite element software. The purpose of this paper is finding out the possibility of making moderately long slabs in industry by metal forming methods. Through this research the strength of required tools for achieving this purpose and the probable flaws and problems during this process accompanied with their solutions have been pointed out.

It has also been of significant importance that the simulation of the problem, i.e. geometrical modeling, material properties, and factors affecting the process, is in harmony with reality and the tools available in Mobarakeh Steel Company.

In the whole simulation process the workpiece has been considered as a cuboid which its length, thickness, and width are respectively 10m, 204mm (0.204m), and 1000mm (1m) and to reduce analysis time, deformation of only 3m of that has been studied.

It should be mentioned that after passing about only 1m of workpiece from rolling shelve, the results converge to steady ones which are desired results and continuing the analysis after that is only to become certain about the accuracy of the results.

The properties of the modeled material are like that of low carbon steel 1015. Moreover, the Young modulus of the material in this temperature regarding the proposed relation $E=-0.1413\times T + 210.81$ is considered about 35 GPa and the Poisson modulus and density of the material are respectively chosen to be 0.33 and 7800 kg/m^2.

In order to model the contact between rollers surfaces and slab, the coefficient of friction in the whole simulation process, as it is usual in hot forming, has been assumed constant and estimated about 0.3. In addition, considering high functionality of explicit finite element code in domain of quasi static problems like forming problems, this method of solution has been implemented to analyze problems.

IV. forming Tools and Work-pieces Dimensions in Each Session

In this part, firstly, it has been focused on the geometry and dimensions of edger rollers which are used to reduce specimens' width. In the first three states, as shown in Fig. 5, the simulation of slab deformation using flat roller, shallow caliber roller, and deep caliber roller has been done respectively and desired outputs such as rolling force, stress and strain contours, and graphs of each have been extracted. It should be noticed that in order to obtain accurate results, the whole simulation process has been done in 3D.

In this stage, parts assembly has been accomplished in such a way that width reduction due to lateral rolling becomes 50mm. The linear speed of rollers has been assumed constant and equal to 1m/sec. the products of lateral rolling, after exiting the first shelve, enter the second shelve in which they undergo a 30mm thickness reduction.

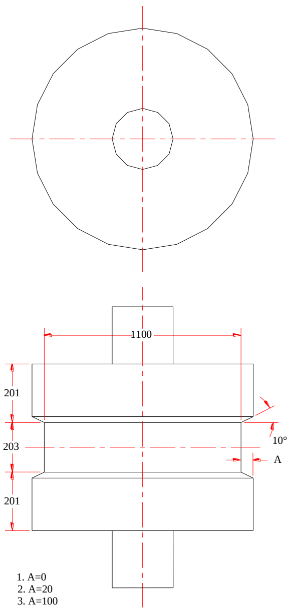


Fig. 5: A=0: flat roller, A=20: shallow caliber roller, A=100: deep caliber roller

Geometry and dimensions of horizontal roller of second stage are shown in Fig. 6.

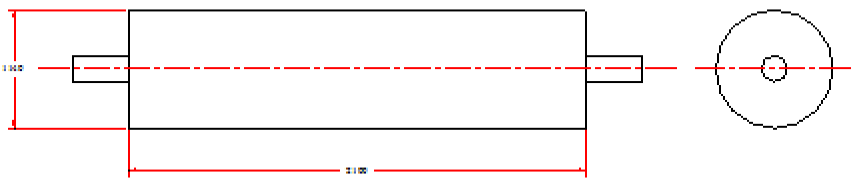


Fig. 6: Geometry and dimensions of flat rollers

The linear speed of rollers has been assumed 2m/sec in slab's thickness reduction stage. In second phase of the simulations, geometric effects of curved rollers on slab deformation, rolling force, uniformity of exerted strain, and etc. have been studied and analyzed. Geometry and dimensions of these rollers are shown in Fig. 7.As shown in figures, simulations consist of studying the effect of using two rollers with depth of 50 and 100mm. In each state by changing the distance between rollers, low (20mm), moderate (50mm), and high (150mm) widths reduction has been studied respectively. The products of lateral rolling, after exiting the first shelve, enter the second shelve in which they undergo a 30mm-thickness-reduction.

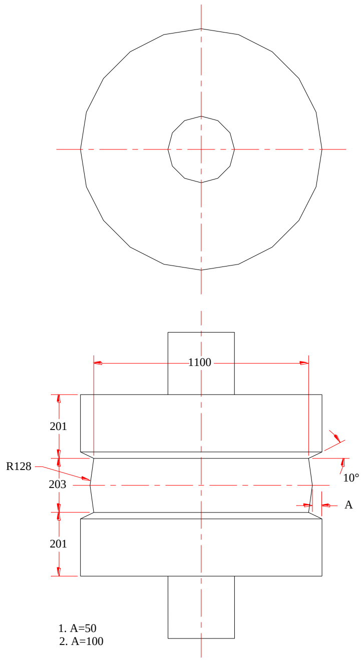


Fig. 7: Geometry and dimensions of curved rollers of interest

Henceforth, to simplify the job, simulations are shown by integers 1 to 9 as illustrated below:

Simulation 1: related to slab's width reduction of 50mm using smooth flat roller and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 2: related to slab's width reduction of 50mm using caliber flat roller with 20mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 3: related to slab's width reduction of 50mm using caliber flat roller with 100mm-dept groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 4: related to slab's width reduction of 150mm using caliber curved roller with 50mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 5: related to slab's width reduction of 50mm using caliber curved roller with 50mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 6: related to slab's width reduction of 20mm using caliber curved roller with 50mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 7: related to slab's width reduction of 150mm using caliber curved roller with 100mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 8: related to slab's width reduction of 50mm using caliber curved roller with 100mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers

Simulation 9: related to slab's width reduction of 20mm using caliber curved roller with 100mm-depth groove, and a subsequent thickness reduction of 30m using horizontal rollers.

V. Results and Discussion - The Results of Slab Deformation Analysis Using Flat Rollers (Simulations 1-3), Curved Rollers (Simulations 4-9), and Conclusion

5.1 Study of points' coordinate displacement changes

In order to study points' coordinate displacement, a set of nodes have been defined for software as the desired outputs. If the workpiece section gets divided into four equal pieces, due to symmetry of nodes flow, the displacement and flow of the nodes can be predicted by studying each quarter of workpiece section. So, the node 5768 in following figure would be exactly at the center of the part. At this stage, the outputs on the nodes highlighted with red color have been extracted.

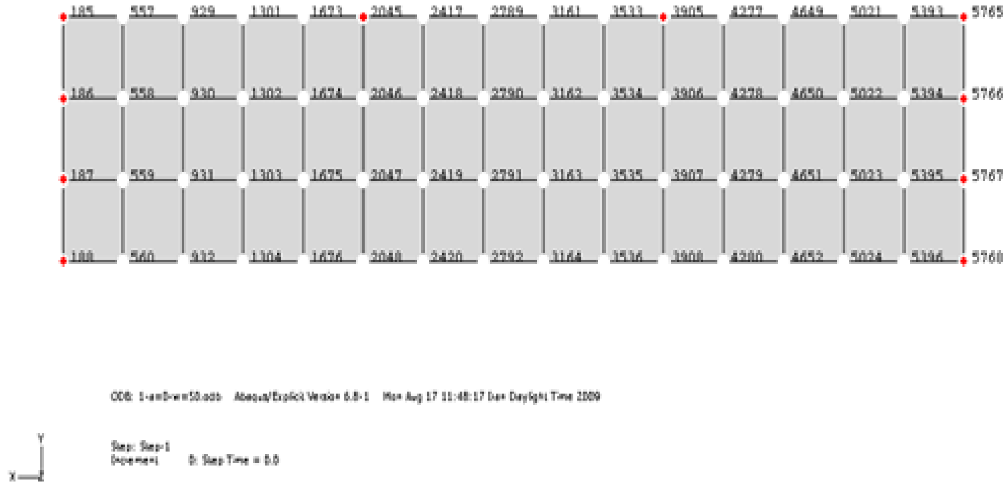
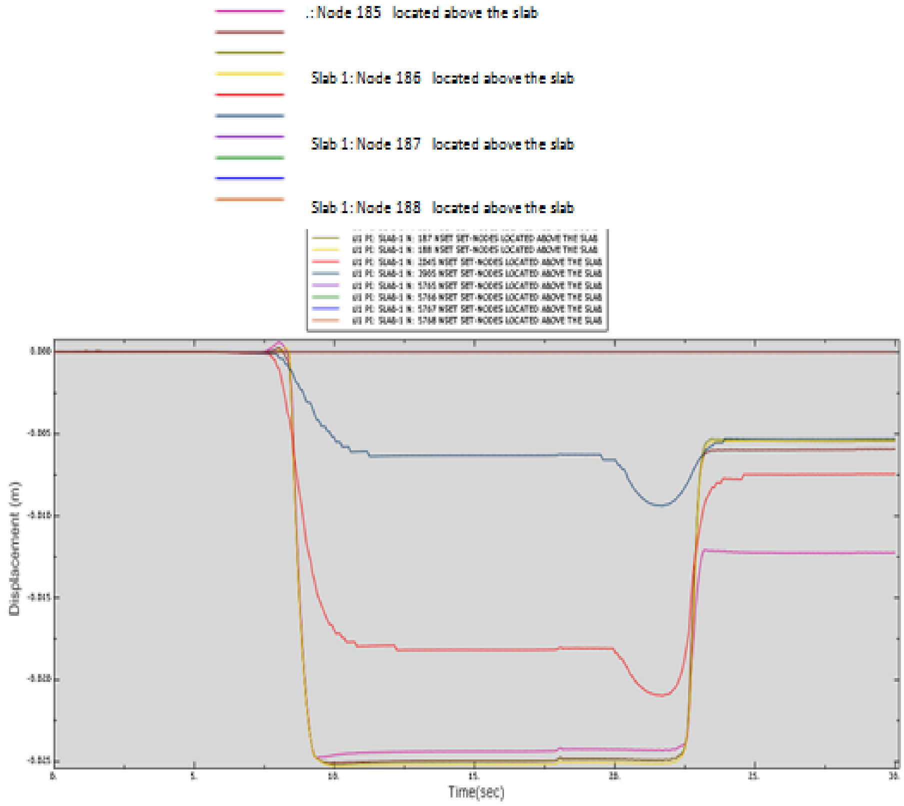


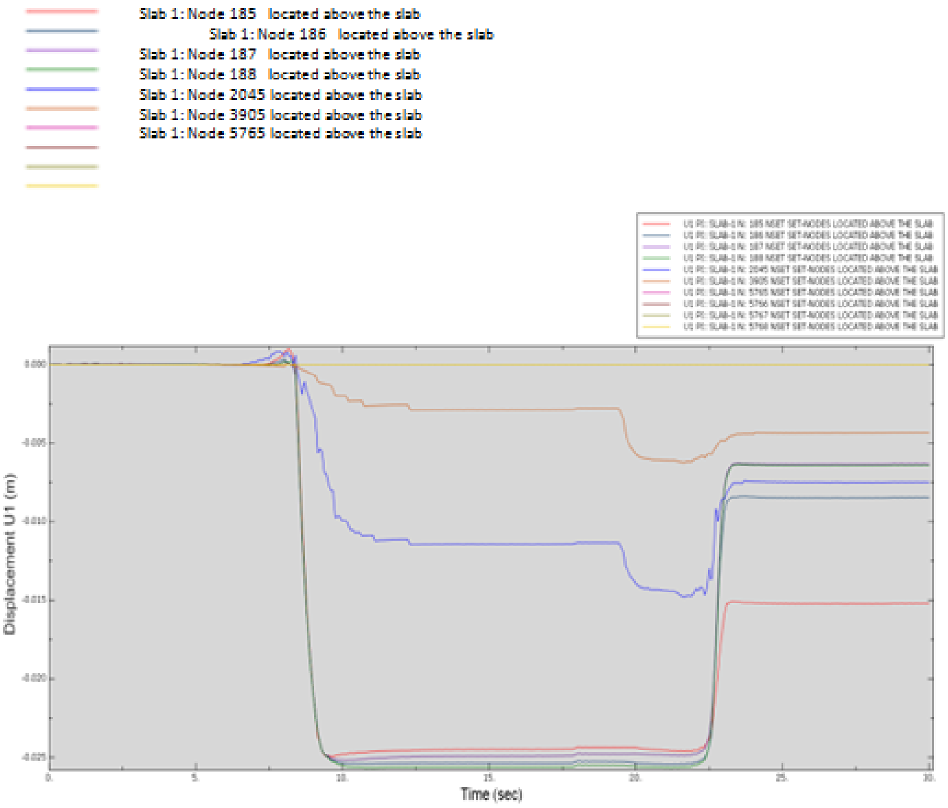
Fig. 8: Defined nodes to extract displacement

5.1.1 Horizontal displacement of defined nodes

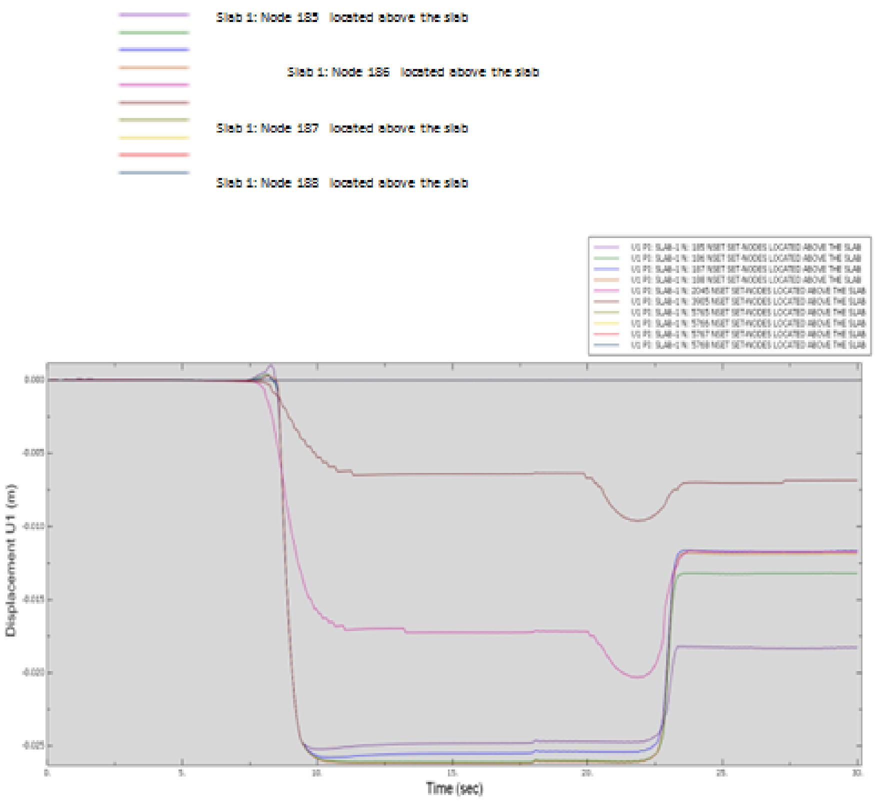
Horizontal displacement of defined nodes (along x axis) related to simulation 1-9 are shown in following figures.



(a)

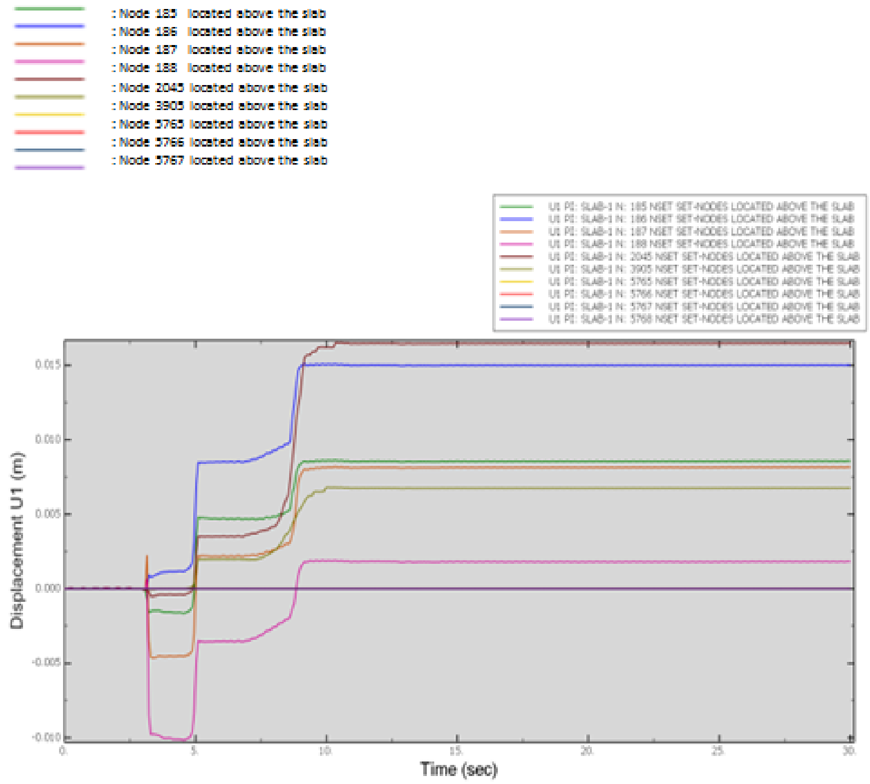


(b)

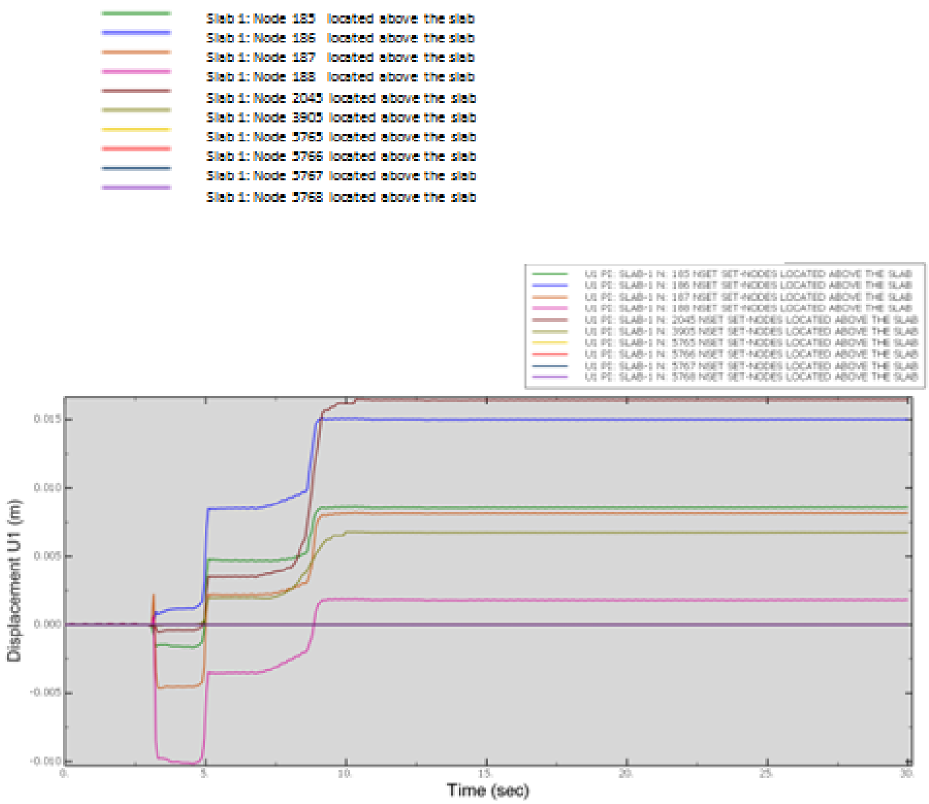


(c)

Fig. 9: Displacement of defined nodes along x axis respectively related to (a): smooth flat rollers, (b): shallow caliber flat rollers (20mm), and (c): deep caliber flat rollers (100mm) (simulation 1-3)

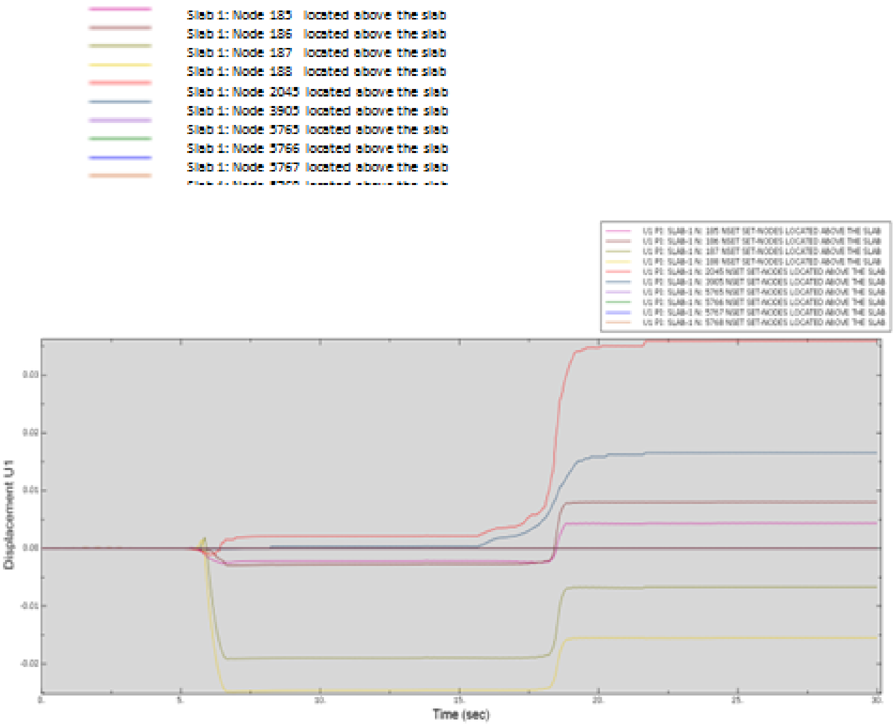


(a)

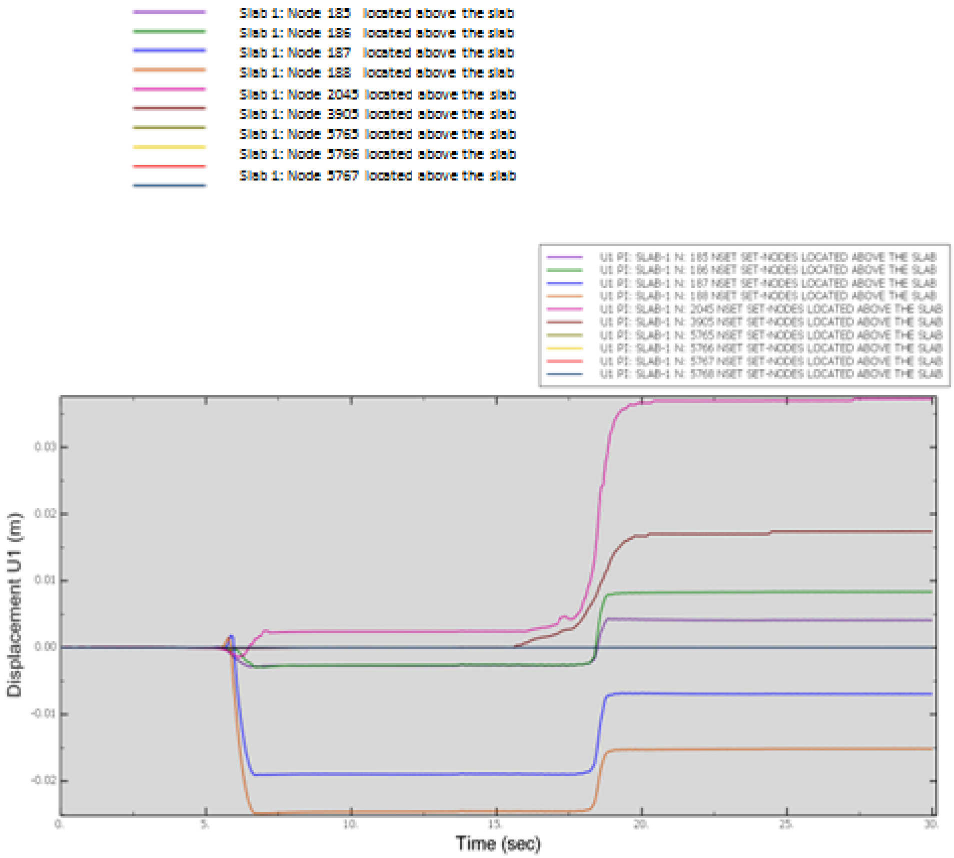


(b)

Fig. 10: Displacement of defined nodes in cross section of 20mm-width-reduced parts along x axis respectively related to (a): caliber curved rollers with 50mm-depth grooves and (b): caliber curved rollers with 100mm-depth grooves (simulations 4, 5)

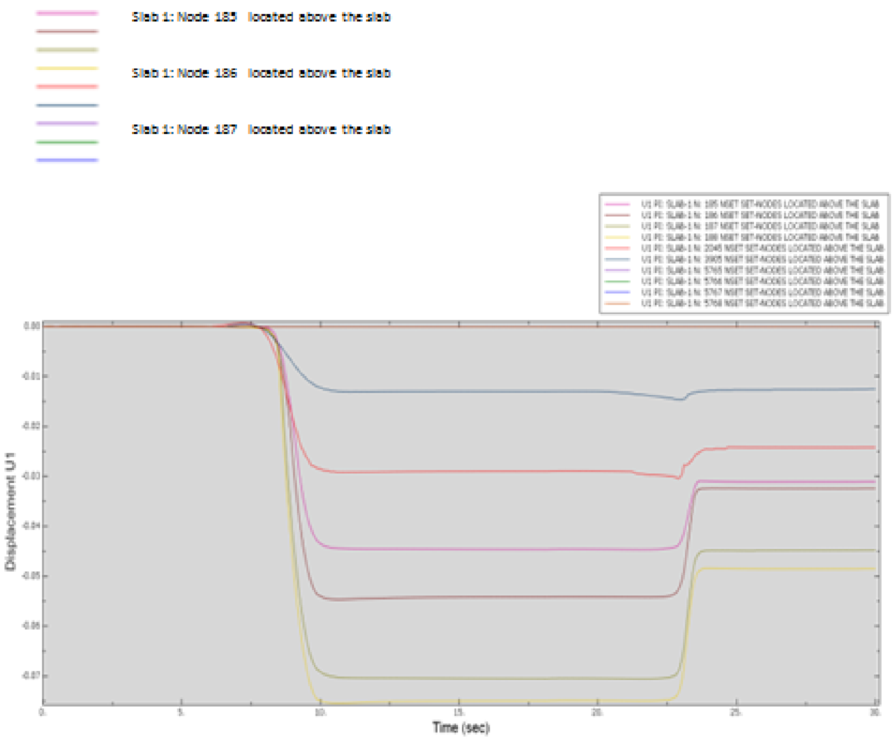


(a)

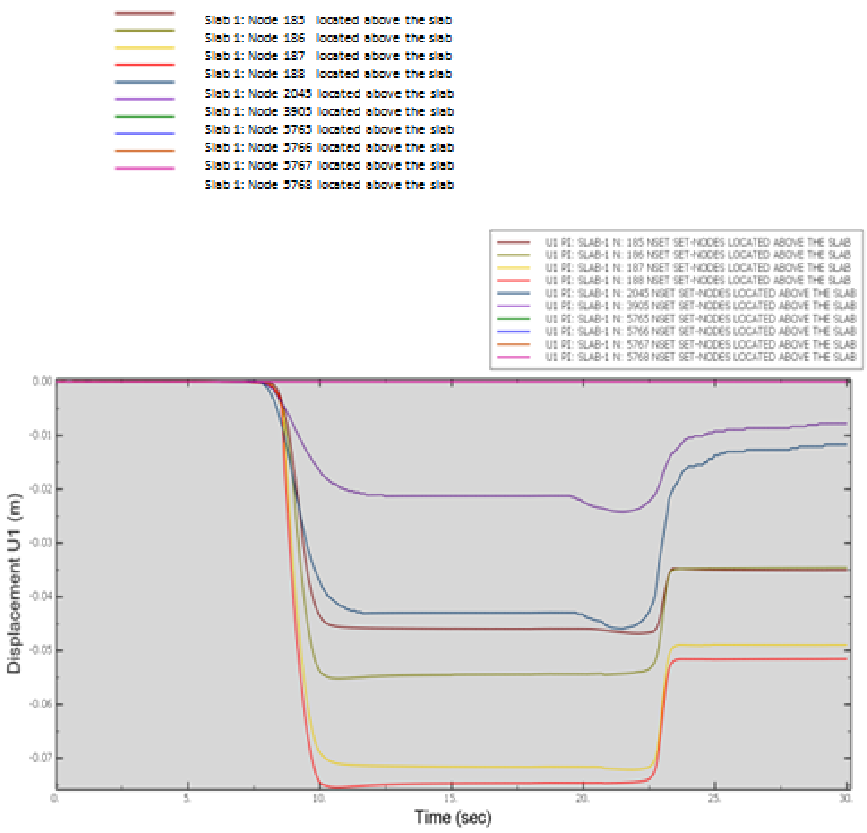


(b)

Fig. 11: Displacement of defined nodes in cross section of 50mm-width-reduced parts along x axis respectively related to (a): caliber curved rollers with 50mm-depth grooves and (b): caliber curved rollers with 100mm-depth grooves (simulations 6, 7)



(a)



(b)

Fig. 12: Displacement of defined nodes in cross section of 50mm-width-reduced parts along x axis respectively related to (a): caliber curved rollers with 50mm-depth grooves and (b): caliber curved rollers with 100mm-depth grooves (simulations 8, 9)

As expected, displacement of most of the points after passing the first shelve and undergoing width reduction is toward the center of the part (negative) and after passing the second shelve and undergoing thickness reduction is toward outer edges of the part along x axis. In addition it is obvious that maximum displacement is related to nodes 185-188 which are in direct contact with roller surface.

5.1.2 Displacements of nodes along normal direction

Displacements of defined nodes along normal direction (along *y* axis) regarded to simulation 1-9 are shown in the following figures. Based on these figures, in order to study nodes movement and show dog-bone shape in slab, nodes displacement at specimen width and its free surface along *y* axis should be studied.

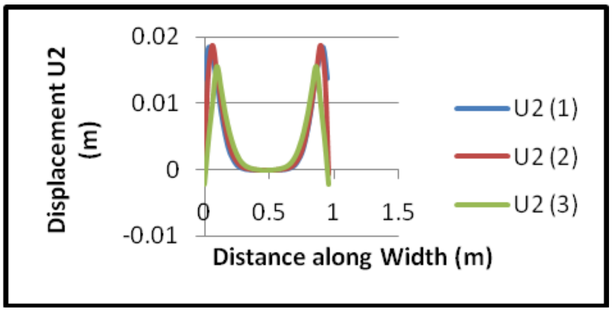
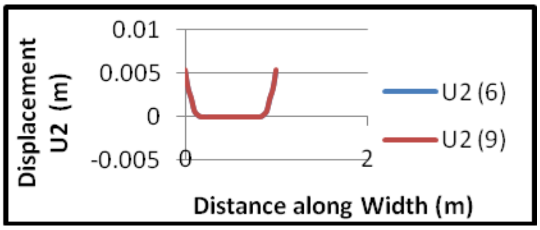
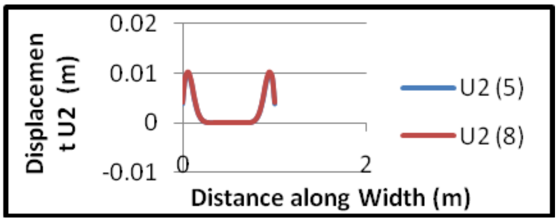


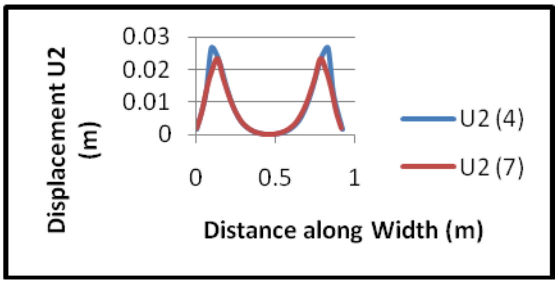
Fig. 13: Comparison of nodes displacement graphs at slab width along normal direction (simulation 1-3)



(a)



(b)



(c)

Fig. 14: Comparison of nodes displacement graphs at slab free surface along normal direction (a): 20mm width reduction (b): 50mm width reduction (c): 150mm width reduction (simulations 4-9)

Considering above graphs, it can be concluded that by increasing groove depth on rollers, dog-bone area gradually moves toward inside the part and its intensity decreases.As shown in figures, due to specimen width reduction, most of defined nodes move toward upside and after that because of passing through second rolling shelve and undergoing thickness reduction they move downward. It can also be concluded that by using caliber rollers, nodes upward movement in the first stage of deformation get limited.

5.2 Force graphs analysis

A summary of results regarded to rolling forces and axial forces exerted on rollers are shown in the following table.

Table 1: A summary of results regarded to exerted rolling and axial forces on rollers in different states

	Width reduction rolling force (KN)	Width reduction axial force (KN)	Thickness reduction rolling force (KN)	Thickness reduction axial force (KN)
Simulation 1	3250	600	13000	600
Simulation 2	3500	1000	13000	500
Simulation 3	4000	2250	13000	400
Simulation 4	5700	1750	15000	650
Simulation 5	2500	500	13000	600
Simulation 6	1250	325	12500	650
Simulation 7	5800	2250	13000	550
Simulation 8	2500	625	12500	600
Simulation 9	1250	325	12000	600

As can be con be concluded from the table, as the groove depth increase, the axial force exerted on rollers increase dramatically.Generally speaking, the more width reduction, the more rolling force required. It can also be concluded that by increasing groove depth on rollers, force increase slightly which is due to caused constraint on upward material flow and pressure increment of deforming material to roller surface.

5.3 Equivalent strain variation analysis

Generally speaking, maximum strain concentration is at slab edges which are in direct contact with rollers. In addition, by increasing groove depth, exerted strain moves toward inside which prevent the workpiece from deforming in normal direction. It can be generally concluded that by increasing groove depth, there will be more uniformity in the workpiece strain.

Also, in each width reduction stage, changing groove depth, does not have a tangible effect on equivalent strain on the part cross section. Moreover, by increasing width reduction, more portion of material undergoes plastic deformation.

5.4 Analysis of residual von misses stress variation

Residual von misses stress usually concentrates on lateral regions of slab which are in direct contact with rollers. This is firstly due to local deformation in these regions which cause stress gradient and eventually residual stress, and secondly because of friction between workpiece and rollers surfaces which prevent from a uniform deformation.

VI. Conclusion

In this paper, the results of using caliber rollers in width reduction process of Hot Rolling Area of Mobarakeh Steel Company were presented. Experimental results obtained from hot rolling manufacturers showed that in case of proper choosing of the caliber rollers, efficiency of edging process increases from 30% to about 70. Based on the results of this research, it was recommended to modify the roller type from flat to caliber. According to this study, using caliber rollers resulted in reduction of dog bone, improvement of edging efficiency and enhancement of stability of the edging process.

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