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INDUSTRIAL USAGE OF COLD ROLLED MATERIALS IN THE ROLLFORMING PROCESS

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***Abstract:** The roll forming process shapes sheet metal using cylindrical rollers to create specific profiles. It's known for high production speed and volume. Demand for strong yet lightweight profiles has risen, but the supply chain for high-strength coil sheet material is a challenge. To meet this demand, this study explores creating profiles from coiled sheet material with improved mechanical properties through cold rolling. The cold rolling process enhances material properties, enabling the use of specialized materials in roll forming. S355MC sheet material was used, and its thickness reduced by 0.1mm through cold rolling. By analyzing the mechanical properties before and after cold rolling, we designed a rectangular profile using FEA software. This resulted in increased yield values along the profile, from 370MPa to 520MPa, achieving the desired mechanical properties.*

***Key words:** Cold forming, Roll forming, Mechanical Property, Strain hardening, FEA.*

1. INTRODUCTION

In recent times, there has been an increasing demand in various sectors to reduce the weight of profiles. This demand is primarily motivated by factors such as the cost of sheet materials and the growing need for lightweight constructions. Achieving a decrease in profile weight necessitates the use of thinner sheet materials. However, when the thickness of the sheet material is reduced, the properties of the sheet grade must be upgraded to maintain the same level of strength. It is also important that the raw materials used are competitively priced and readily available.

The rolling technique offers a means to transform and enhance the mechanical strength values of widely used sheet materials in the market. By utilizing the rolling method, the raw material can be shaped and formed using the rollforming technique. Cold-rolled materials have extensive industrial usage in the rollforming process. Rollforming is a widely employed method for shaping sheet metal into continuous profiles with consistent cross-sections.

The purpose of this study is to investigate and analyze the practical applications of cold-rolled materials in the rollforming process within an industrial context. This study specifically investigates the production of special profiles using the rollform technique, with a primary emphasis on sheet metal that has undergone a rolling process resulting in altered mechanical properties. The aim is to examine the feasibility and effectiveness of producing these profiles using this method.

1.1 Cold Forming

Sheet forming operations can be classified, as depicted in Figure 1 [1]. Cold forming is a process where the material is shaped permanently without any chemical changes, typically performed below the recrystallization temperature. Marciniak and Duncan [2] have identified numerous techniques employed in sheet metal forming. Various methods are used for shaping sheet metal, including bending, curling, ironing, laser cutting, hydroforming, and punching. During the shaping process, sheet materials exhibit nonlinear behaviour, which can be attributed to plasticity. Plasticity is the study of the nonlinear stress-strain relationship in materials. Many engineering materials commonly exhibit varying degrees of nonlinear stress-strain behaviour, ranging from relatively simple curves, as shown in Figure 2, to more complex curves in Figure 3 and even highly nonlinear behaviour in Figure 4 [3].

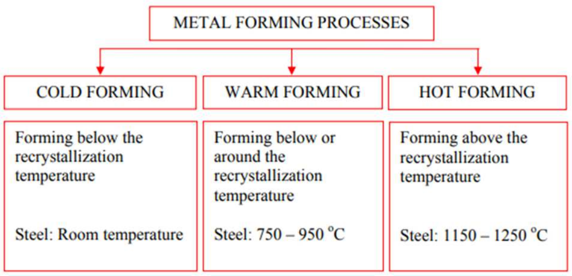

Fig. 1. Classification of Sheet Forming [1].

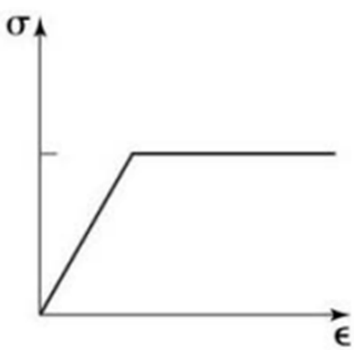

Fig. 1. Simple Curve [3].

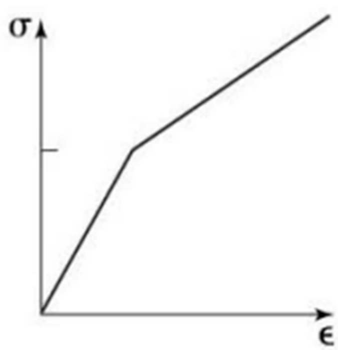

Fig. 2. Next Simplest Curve [3].

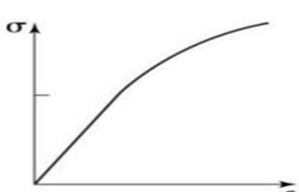

Fig. 3. Highly Nonlinear Curve [3].

Rollform (Figure 5) is part of bending processes. Roll form technique is to form sheet metal strip along straight, longitudinal, parallel bend lines with multiple pairs of contoured rolls without changing the thickness of the material at room temperature [4]. Rollform machines are typically composed of multiple stations that are identical to each other. It is a technique that is widely utilized in many areas such as construction, automotive, greenhouse and storage due to its low operating costs. Among the biggest advantages offered by the rollform process are high production volume and low labor use. The main disadvantages are, forming steps and load distributions determined correctly. Designer and production staff should be experienced in order to design and installation.

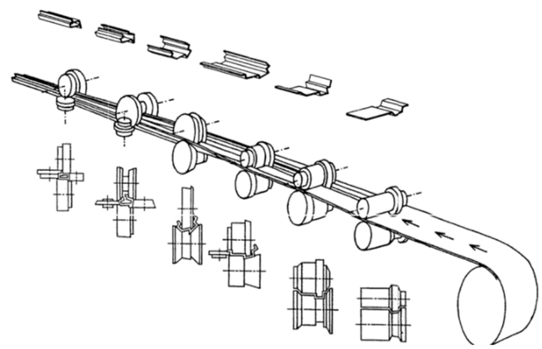

Fig. 5. Rollform Flow Chart.

1.2 Cold Rolling

The process of plastic shaping by passing the materials between two rollers rotating around their axis is called rolling. It is the most widely used plastic forming method due to its production speed and continuity and ease of process and product control [5]. Figure 6 shows a rolling assembly consisting of two rollers. As the workpiece passes between two rollers in the cold rolling process, the thickness of the material gradually decreases. This reduction in thickness occurs due to the compressive forces exerted by the rollers, which reshape the material into the desired profile. The gradual reduction in thickness between the rollers is a key aspect of the cold rolling process. It allows for controlled deformation of the material, ensuring that the desired thickness is achieved without causing excessive strain or damage to the workpiece.

The amount of thickness reduction depends on various factors such as the material properties, roller design, and specific cold rolling parameters. The gap or distance between the rollers is adjusted to achieve the desired thickness reduction, ensuring that the rolled product meets the required specifications.

It is important to carefully control and monitor the thickness reduction during the cold rolling process to maintain dimensional accuracy and the structural integrity of the profile being formed. Proper calibration and adjustment of the rollers help achieve consistent and precise thickness reduction for high-quality cold rolled products.

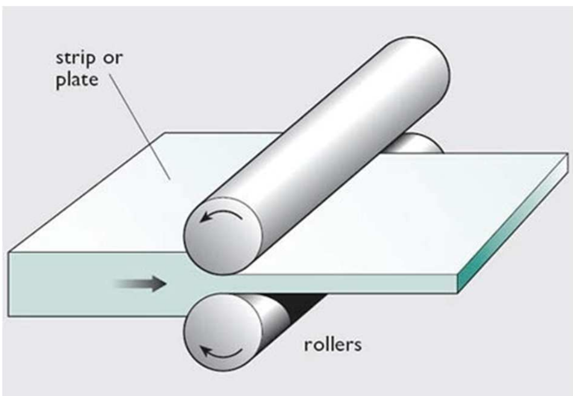

Fig. 6. Cold Rolling Processes.

- Cold rolling is gain to new mechanical properties which indicated as below to flat product in room temperature.
- Precision thickness is provided which hot rolling is not achieved due to supercooling.
- In order to control the microstructure, mechanical properties such as tensile and strength gains features.
- Eliminating the oxide layers and providing the desired level of roughness, it gains features such as final quality surface appearance and gloss.
- Flatness tolerances can be provided.

During the cold rolling process, as the metal undergoes mechanical stress, it initiates a lasting alteration in the crystal structure of the material (Figure 7). This leads to a notable enhancement in the material's strength and often strengthens its resistance to corrosion. Beyond the notable benefits of augmenting surface quality, cold rolling also confers the advantage of significantly improved dimensional accuracy. The mechanical manipulation of the metal during cold rolling not only fortifies its structural integrity but also refines its overall performance characteristics, rendering it a preferred choice in various industrial applications.

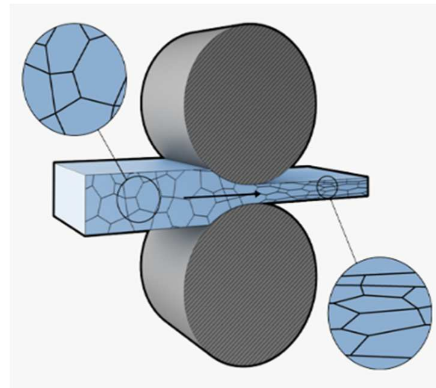

Fig. 7. Extended Grains.

2. MATERIAL AND METHOD

To observe and evaluate the mechanical strength of the cold-rolled strip material in the rollforming process, the thickness of 1.70mm S355MC material was reduced to 1.60mm, and its condition before and after cold rolling was examined. The sheet, after undergoing the thickness reduction process, is denoted as R-S355MC. The assessment of material mechanical properties assumes significance in evaluating the plastic behavior of the material in the rollforming process.

The mechanical properties of both the 1.70mm S355MC material and the cold-rolled 1.60mm S355MC material were determined through a tensile test, a common method employed to ascertain material characteristics such as yield strength (YS), ultimate tensile strength (UTS), and elongation percentage [6]. These parameters serve as crucial inputs for Finite Element Analysis software, which is employed for characterizing the mechanical properties of deformable materials.

The results derived from the conducted tensile test (Figure 8) have been recorded within Table 1. However, it is of paramount significance to underscore that, in the context of subsequent analysis and evaluation, the specific data gleaned from Table 1 assumes a essential and irreplaceable role.

Fig. 8. Tensile Test.

Table 1

Data point of R-S355MC

Data point	Tensile Rm N/mm	Yield Re N/mm	Elongation %A
S355MC	550Mpa	410Mpa	%21
R-S355MC	615Mpa	549Mpa	%14

It was observed that the yield and tensile stress of the sheet which reduced thickness is increased. However, the difference between yield and tensile stress decreased as expected. In addition, it is observed that total elongation is decreased. The engineering stress-strain curve, based on the original length (L_o) and cross-sectional area (S_o) of the tensile specimen, does not provide an accurate representation of its deformation. This is because the curve does not consider the significant reduction in S_o that occurs after necking.

Consequently, the engineering stress-strain curve decreases until fracture takes place. Necking, which refers to localized deformation, typically begins at the maximum load, where the stress increment resulting from the decrease in the specimen's cross-sectional area outweighs the material's capacity to carry the load [7].

It is more meaningful to use a true stress–true strain scheme. σ_T is defined as the load F divided by the instantaneous cross-sectional area over which deformation is occurring (i.e., the neck, past the tensile point), or

$$\sigma_T = \frac{F}{A_i} \text{ [8]} \quad (1)$$

Furthermore, it is occasionally more convenient to represent strain as true strain ε_T, define by

$$\varepsilon_T = \ln\left(\frac{l_i}{l_0}\right) \text{ [8]} \quad (2)$$

If no volume change occurs during deformation, that is, if

$$A_i l_i = A_0 l_0 \text{ [8]} \quad (3)$$

True and engineering stress and strain are related according to

$$\sigma_T = \sigma(1+\varepsilon) \text{ [8]} \quad (4)$$

$$\varepsilon_T = \ln(1+\varepsilon) \text{[8]} \quad (5)$$

The utilization of these equations enables a more realistic depiction of the material's behavior in the rollforming process. In classical bending methods, the strain of the bending region in the material is examined using the K-factor.

However, this method alone is insufficient for analyzing the roll forming process. One of the key distinctions is that, in addition to shear stresses, the sheet material experiences normal stresses in the roll forming process, whereas in classical sheet bending methods, it is only exposed to shear stresses [9].

Using the data obtained from the tensile test, the real tensile curve is defined in the finite element program with these necessary transformations. Identify data points for S355MC and R-S355MC are shown in Tables 2 and 3.

Table 2

Data point of R-S355MC

MPa	%Strain
519.89	0
552.24	0.39

565.15	0.405
570.31	0.453
575.34	0.429
578.71	0.485
582.28	0.509
585.61	0.548
587.65	0.596
589.46	0.628
590.95	0.683
592.50	0.691
593.81	0.715
594.94	0.770
595.41	0.762
596.53	0.857
597.65	0.897
597.79	0.952
598.57	0.991
598.66	1.023
599.19	1.055
599.42	1.094
599.86	1.165
600.63	1.189
600.96	1.267
601.16	1.307
601.63	1.307
602.03	1.385

It is essential to construct an accurate representation of the actual tensile curve within the finite element program. This necessitates the application of crucial transformations to integrate the experimental results into the computational model.

Considering this, particular attention is directed towards the data points associated with S355MC and R-S355MC materials, as they play a vital role in effectively calibrating the model.

Table 3

Data point of S355MC

MPa	**%Strain**
428.30	0
456.02	0.01
475.83	0.02
492.50	0.03
507.00	0.04
519.81	0.05
531.26	0.06
541.57	0.07
550.92	0.08
559.44	0.09
567.24	0.10
574.42	0.11
581.06	0.12
587.23	0.13
592.97	0.14
598.35	0.15
621.07	0.20
654.93	0.30
682.71	0.40
708.59	0.50
733.87	0.60
758.95	0.70
783.98	0.80
808.99	0.90
833.99	1

The process of identifying the real curve within finite element analysis software involves several critical steps that are integral to the accurate representation of material behavior and performance in a simulated environment. Figures 9 and 10 depict the results of this identification process, showcasing the transformation of raw experimental data into a format suitable for computational modeling.

The accuracy of this real curve representation is paramount in ensuring that the finite element analysis provides reliable predictions and insights into the material's behavior. It enables engineers and researchers to assess the structural integrity of components, predict failure points, and optimize designs without the need for extensive physical testing, thus saving time and resources in the product development process.

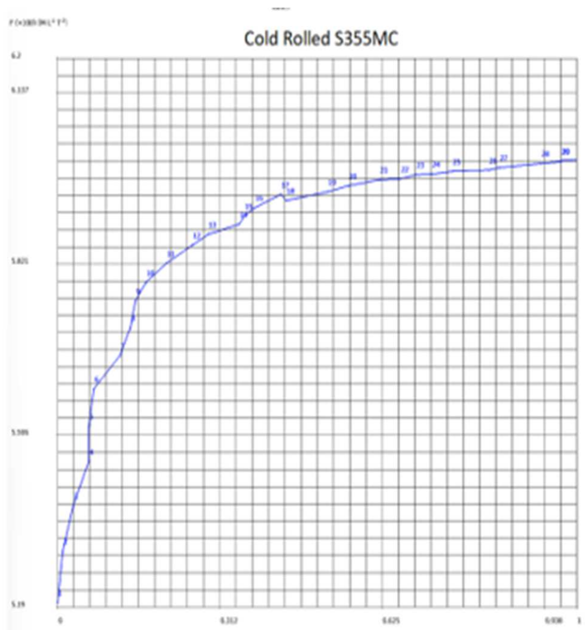

Fig. 9. Colled Rolled S355MC.

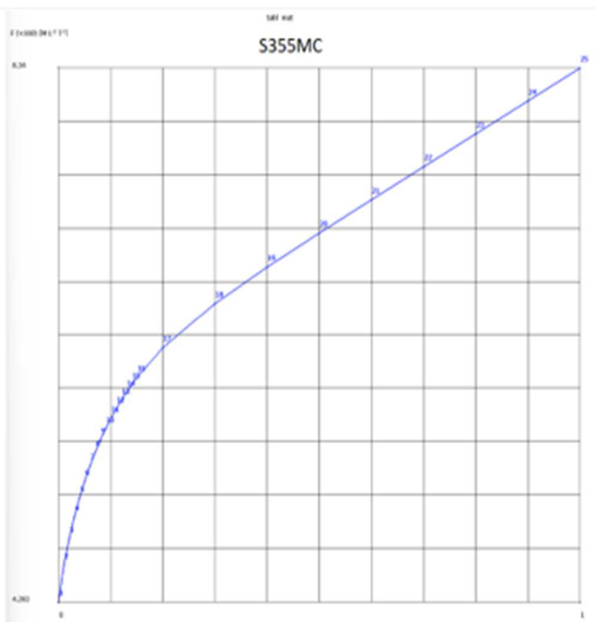

Fig. 10. S355MC.

Within this research, the tool design employed adhered to a rectangular shape measuring 55x55mm. The production process for crafting a thin-walled, heterogeneous rectangular welded tube involved the direct bending of a steel plate into the desired rectangular configuration. Following this, the shaped tube was joined through the application of high-frequency resistance welding, as described in reference [10]. To obtain rectangular section profiles, the tubes were compressed in the rollform line using units known as squeeze rollers. The required pipe sizes and compression ratios were determined using Copra RF software, which aided in achieving the desired rectangular profile. The forming steps involved in the process are illustrated in Figure 11.

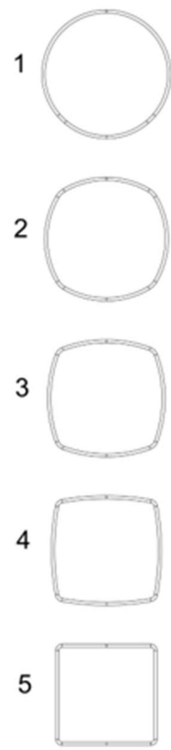

Fig. 11. Forming steps.

COPRA FEA RF is used for analyzing the behavior of the materials. Boundary conditions and ignorance for the finite element analysis are:

- Friction between rolls and material is not taken into account.
- Rotational movement of the rolls is not considered.
- The mechanical properties of the material are assumed to be homogeneous throughout the entire strip.
- In the tube, the strain hardening gained from the previous process is omitted.
- Rollers and roll shafts are presumed to have infinite rigidity.

Same tube dimensions, same tools, and same conditions are used for both materials. The mold design was created based on the sheet forming steps. The designed molds and the material curves are defined in FEA software. In accordance with the analysis results, the new yield strength values for S355MC and R-S355MC are depicted in Figures 12 and 13.

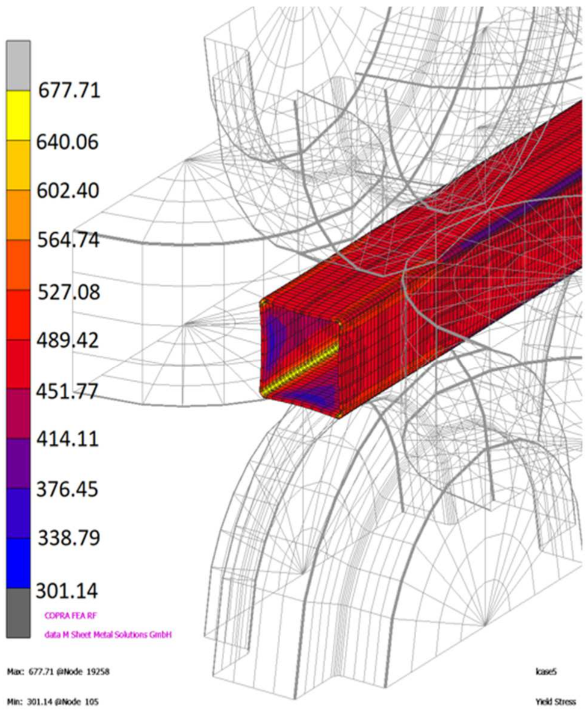

Fig. 12. S355MC new yield strength values.

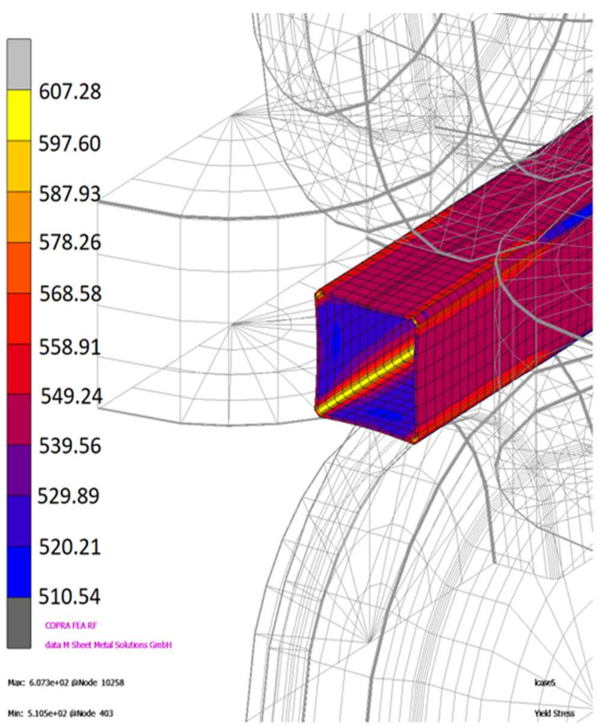

Fig. 13. R-S355MC new yield strength values.

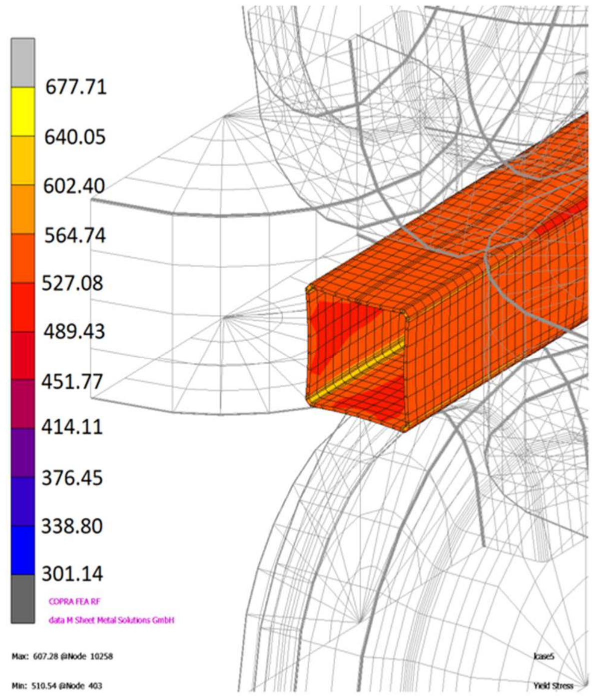

Fig. 14. R-S355MC results with S355 yield label scale values.

3. RESULTS AND DISCUSSION

The central objective of this research is to significantly improve the mechanical properties of steel sheets by employing the cold rolling method. The primary focus is directed towards the subsequent phase of manufacturing profiles using these processed sheets. To offer a thorough and detailed comprehension of the research findings, it is imperative that we delve deeply into the specific methodologies, procedures, and outcomes of this study.

In the initial phase of this study, a specific material was carefully chosen as the starting point: a S355MC steel sheet with a thickness measuring 1.7mm. This material selection was made based on its relevance to the research objectives and its suitability for the subsequent processes.

To facilitate the desired modifications and enhance the material's properties, a well-established method known as cold rolling was employed. This technique involved systematically reducing the thickness of the original 1.7mm steel sheet by precisely 0.1mm. The cold rolling process is a widely recognized method in metallurgy and materials science for altering the physical and mechanical properties of metallic materials.

As a result of this meticulous processing, the mechanical properties of the steel sheet underwent significant changes. These alterations in mechanical characteristics were thoroughly examined and are meticulously depicted in Figure 9. This graphical representation serves as a valuable resource, offering detailed insights into how the material's properties evolved as a consequence of the cold rolling process.

Furthermore, Figure 10 provides an additional layer of detail by presenting an updated material curve. This curve offers a comprehensive view of the material's behavior and properties, considering the modifications brought about by the cold rolling procedure. Such comprehensive visual representations are indispensable for understanding the nuanced changes in mechanical properties and material behavior that occurred during the course of this study.

Upon close examination of the results, it becomes evident that there have been notable improvements in the yield strength and tensile strength of the sheet. This is a direct consequence of the 0.1mm reduction in thickness achieved through the cold rolling process.

The yield strength represents the maximum stress the material can withstand without undergoing permanent deformation, while the tensile strength denotes the maximum stress it can endure before fracturing. In both cases, there is a noticeable increase, indicating improved mechanical performance.

However, one significant consideration is the total longitudinal elongation of the sheet, which has decreased. Longitudinal elongation refers to the material's ability to stretch before breaking. In this context, the reduction in elongation suggests a decrease in the material's formability, which means it may become more challenging to shape the sheet into desired profiles. This decrease in formability is a significant aspect to consider when evaluating the trade-offs for the enhanced mechanical strength achieved through cold rolling.

To gain further insights into the implications of these changes, the material curves for both S355 and R-S355MC have been defined within a finite element analysis program. This allows for a thorough analysis of the new yield points on the profile under the same boundary conditions and using the same tools.

In Figure 12, it is observed that the maximum new yield stress for S355MC is approximately 677 MPa, with the maximum new yield point situated at the corner points of the profile. On the other hand, the minimum new yield stress, averaging 370 MPa, is predominantly found on the straight edges.

In Figure 13, the maximum new yield stress for S355MC is around 607 MPa, and once again, the maximum new yield point is located at the corner points of the profile. The minimum new yield stress, averaging 520 MPa, is predominantly observed on the straight edges.

It's worth noting that when the new yield limits of the S355MC sheet, which underwent the 0.1mm cold rolling process, were applied to the yield scale of the R-S355MC sheet, a significant increase in the minimum yield values on the straight edges was observed, elevating them from 370 MPa to 520 MPa.

This suggests that profiles manufactured from R-S355MC, a rolled material, may exhibit superior mechanical performance due to the increased yield values on the straight edges compared to profiles produced from S355MC material.

However, it's crucial to consider another aspect: the material's performance under loading conditions, particularly its propensity to fracture in the bend corners. This aspect warrants thorough evaluation to ensure a comprehensive understanding of the material's behavior in practical applications.

4. CONCLUSION

Roll forming process is a production method that is shaping the sheet metal strip station by station via cylindrical rollers to obtain the desired profile section.

The prominent features of the roll forming process compared to other sheet metal forming processes are its high production volume and high production speed. Due to the wide usage area of sheet profiles, it is expected to produce profiles with distinct mechanical properties with the roll forming process. In recent times, the tendency to reduce weight without reducing inertia in systems and mechanisms where profiles are used has increased the demand in profiles with high mechanical properties. However, due to the issue of supply chain of high mechanical properties coils sheet material as well as requirement of special properties coils in most sectors, the demand of coil sheet material whose mechanical values have been changed has arisen.

In order to meet this demand, the production of profiles from coiled sheet material, whose mechanical values are improved by using cold rolling method, is examined within the scope of this study. With a rolling process as small as 0.1mm, the mechanical values of the sheet material can be increased, and profile production can be made by using the rollform technique.

The stress values required for the deformation of the obtained profile have increased. Therefore, with a higher amount of rolling, the usage area of profiles produced with low grade sheets can be expanded in areas where plastic deformation is not desired.

Considering that the longitudinal elongation is reduced, the strength values of the profiles produced from sheets whose mechanical values are increased by the rolling method should be interpreted according to their usage areas. In addition, it can be aimed to make the sheet whose hardness increased by the rolling method suitable for mass production by carrying out the necessary standardization.

Further research can be conducted to identify specific cold-rolled materials exhibiting enhanced properties for rollforming applications. This can involve exploring different alloys or surface treatments to achieve desired mechanical characteristics and surface finishes. Investigate the environmental impact of cold-rolled materials and the rollforming process. Explore methods to reduce energy consumption, optimize material utilization, and implement recycling or waste reduction strategies to enhance the sustainability of the rollforming industry.

By focusing on these future suggestions, the industrial usage of cold-rolled materials in the rollforming process can be further optimized, leading to improved product performance, cost-effectiveness, and sustainability in a wide range of sectors.

5. REFERENCES

[1] Tekkaya A.E., ME 453 Metal Forming Technology, Lecture Notes. (2001): Middle East Technical University, Ankara.
[2] Marciniak, Z., Duncan,J. L., Hu, S., J., “Mechanics of Sheet Metal Forming”, Butterworth-Heinemann, London, (2002).
[3] Robert M. Jones, Deformation Theory of Plasticity (2009).
[4] G.T. Halmos “Roll forming handbook” (2005) ISBN: 0-8247-9563-6.
[5] Aran, A. and Demirkol, M., "Haddeleme", Plastik Şekil Verme Teknolojisi, ITU, Istanbul, (1994).
[6] Davis, J. R., “Tensile testing”, ASM international. (2004).
[7] Shengming Zhang, Richard Villavicencio, in Probability and Mechanics of Ship Collision and Grounding, (2019).
[8] Karachalios, E., Achilles, V. "The study of design of constants in sheet metal forming." Proceedings (2006).
[9] Kiuchi, M., Kodabashi, T, “Proc. of the 3rd International Conf. on Rotary Metalworking Processes”, IFS Ltd and North Holland (1984).
[10] Hailong Liu, Yuli Liu, “Cross section deformation of heterogeneous rectangular welded tube in rotary draw bending considering different yield criteria, “Journal of Manufacturing Processes, (2021).

UTILIZAREA INDUSTRIALĂ A MATERIALELOR LAMINATE LA RECE ÎN PROCESUL DE LAMINARE

Procesul de rulare modelează tabla folosind role cilindrice pentru a crea profile specifice. Este cunoscut pentru viteza mare de producție și volum. Cererea pentru profile rezistente, dar ușoare a crescut, dar lanțul de aprovizionare pentru tablă bobinată de înaltă rezistență este o provocare. Pentru a satisface această cerere, acest studiu explorează crearea de profile din material de tablă bobinată cu proprietăți mecanice îmbunătățite prin laminare la rece. Procesul de laminare la rece îmbunătățește proprietățile materialului, permițând utilizarea materialelor specializate în deformarea prin rulare. S-a folosit tablă S355MC, iar grosimea sa a fost redusă cu 0,1 mm prin laminare la rece. Analizând proprietățile mecanice înainte și după laminarea la rece, am proiectat un profil dreptunghiular folosind software-ul FEA. Acest lucru a dus la creșterea valorilor tensiunii de curgere de-a lungul profilului, de la 370MPa la 520MPa, realizându-se proprietățile mecanice dorite.

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