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Chain-die Forming, is it a right forming method to make structural parts of motor vehicles with UHSS material

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Abstract

Reducing the body weight of a motor vehicle is one of the most important research approaches in car manufacturing and steel making industries in order to reduce the pollution caused by motor vehicles. In this approach, ultra-high strength steel (UHSS) is developed by steel makers and has been applied more and more to motor vehicles. The UHSS materials have the required strength, but more or less the material's ductility is sacrificed to achieve this target. High strength materials are difficult to form using conventional forming methods. Forming high strength materials to parts effectively and economically is a high priority. Chain-die Forming is a newly developed sheet forming method which solves the problem of high redundant strain components during roll forming. Apart from producing uniform profile long and straight products, Chain-die Forming can also be employed to make simpler non-uniform products conventionally by stamping via design and machine the die-blocks to be a pair of stamping dies and then sliced to die-blocks jointed on the chain-links. When the dies are moving forward synchronously following the profiles of track boards, the stamping die-blocks are gradually enclosed to "stamp" the strip. This process then becomes continuous stamping. Such type of forming step can be lined in tandem, and then this process breaks down a typical stamping to a few small forming steps superposing bending and tension/compression instead of complex strain history during stamping. This paper introduces some preliminary studies of Chain-die Forming to UHSS materials and discusses some possible applications to make the structural parts of motor vehicles by Chain-die Forming in the future.

Keywords

forming, chain, motor, vehicles, uhss, material, structural, method, make, parts, right, die

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CHAIN-DIE FORMING, IS IT A RIGHT FORMING METHOD TO MAKE STRUCTURAL PARTS OF MOTOR VEHICLES WITH UHSS MATERIAL?*

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Abstract— **Reducing the body weight of a motor vehicle is one of the most important research approaches in car manufacturing and steel making industries in order to reduce the pollution caused by motor vehicles. In this approach, ultra-high strength steel (UHSS) is developed by steel makers and has been applied more and more to motor vehicles. The UHSS materials have the required strength, but more or less the material's ductility is sacrificed to achieve this target. High strength materials are difficult to form using conventional forming methods. Forming high strength materials to parts effectively and economically is a high priority.**

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This paper introduces some preliminary studies of Chain-die Forming to UHSS materials and discusses some possible applications to make the structural parts of motor vehicles by Chain-die Forming in the future.

I. INTRODUCTION

In today's society the conservation of energy and the reduction of pollution are of high priority. Reducing a vehicle's pollution via reducing its consumption of petrol has become more and more important in the automotive industry. Steel making companies, car makers and research institutes are all working to reduce the weight of motor vehicles without sacrifice to the safety of passengers, while also reducing fuel consumption. Research shows that under the current technology available to automobiles, reducing 10% of a vehicle's body weight results in a 7-10% reduction in the consumption of fuel. This greatly impacts cities with severe pollution problems. The application of UHSS to make structural parts that reduce the weight of a vehicle has been suggested, and is being studied under market requirements to also suit the needs of our modern day society.

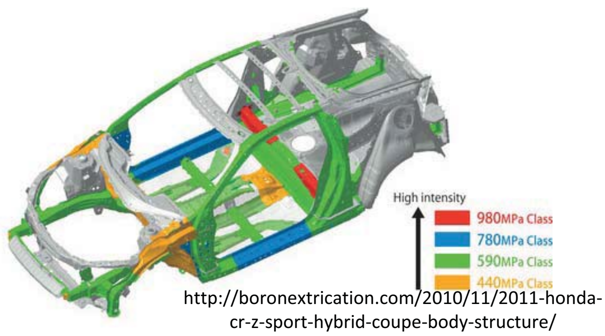

Figure 1. The Body Structure of the 2011 Honda CR-Z is made up with 45% high-strength steel (590 MPa or above)

There are many types of Ultra-High Strength Steels (UHSS), also known as Advanced High Strength Steels (AHSS), available in the market being widely applied in the automobile industry. Currently UHSS includes dual phase (DP), transformation-induced plasticity (TRIP), complex phase (CP), martensite (MART), hot press forming (HPF) steels and twinning-induced plasticity (TWIP) [1-6]. Extra advanced high-strength sheet steel (X-AHSS) has dramatically increased in popularity as of late [1]. Except under developed steels of TWIP and X-AHSS, the other materials mentioned above have the required strength, but their elongation is not so ideal. Typically, some of the aforementioned materials have elongation less than 15% as the strength achieved goes above 800 MPa - this is far lower than the 40% elongation of IF and BH steels. Non-ferrous materials have a similar problem: when high strength is achieved, elongation is diminished. It is a challenge to use these materials for the current processing methods such as roll forming and stamping. The new materials are difficult to stamp directly due to the high strength and limited elongation. To solve the problem, hot stamping has been introduced but it requires more capital investment and the high temperature working environment brings new challenges to the automotive industry [5-8].

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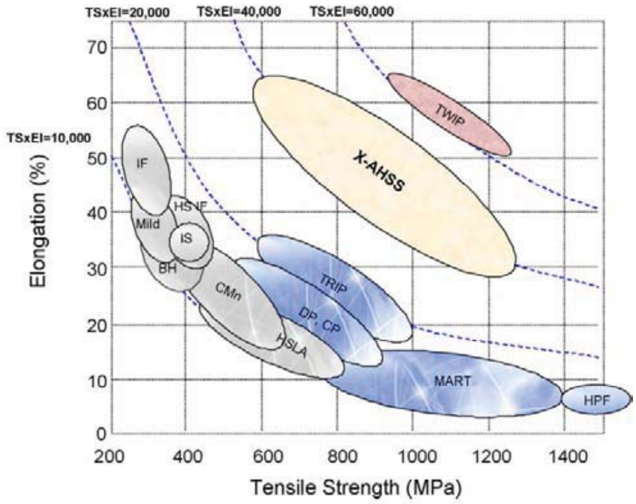
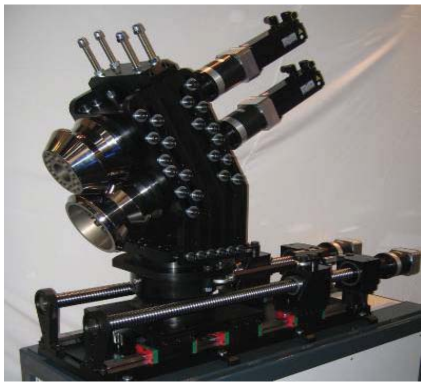


Figure 2. Tensile strength and elongation of UHSS steels [1]

In order to solve these problems, many research institutes are making investments in capital and labour to study and develop roll forming methods that resolve these problems through the use of “bending” to replace “stamping”. To a long straight simple profiled product, high strength means a large press force and large springback, and lower elongation may lead to cracks along the bend when the radius is small. To non-uniform profile products, conventional roll forming is no longer suitable. The replacement is the so-called “flexible roll forming” which employs a computer system to control the positions and angles of the forming rolls [9]. Typical flexible roll forming systems include the one developed by dataM in Germany (as shown in Figure 3) and another one created by the cooperation of Takushoku University and Sanyoseiki Co. Ltd. Even though flexible roll forming can be employed to make some simple non-uniform profile products, the system has some fundamental difficulties which need to be solved as well as other problems such as low operation speed and expensive capital investment. Therefore, there is still some distance from general industrial application. The range of different product types that can be made by flexible roll forming is still not fully defined.

(a) The second generation of DataM flexible roll forming



(b) New design of flexible roll forming station

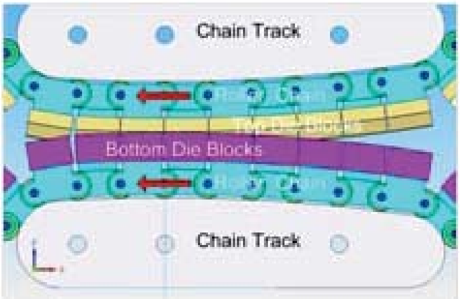
Figure 3. Flexible roll forming system developed by dataM http://www.autosteel.org/~/media/Files/Autosteel/Great%20Designs%20in%20Steel/GDIS%202011/21%20-%20Albert%20Sedlmaier%20-%203D%20Flexible%20Roll%20Forming.ashx

With the development of UHSS being applied in car structures and the problems discussed above, it is highly necessary that a new forming process should replace the conventional forming methods applied to UHSS. The newly proposed and developed forming method, Chain-die Forming, is considered as having high potential to be the most economical and energy saving process, because of its technical characteristics of bending and stamping.

II. Chain-die Forming

Originally, Chain-die Forming was invented to reduce the redundant strain components in conventional roll forming through increasing the length of the deformation zone, via increasing the apparent roll radius [9, 10]. The basic principle is to use discrete die-blocks that simulate the working surface of a roll of very large radius, in order to avoid the occurrence of product defects and improve the quality of products. With a uniform profile, the forming process is more like that of an air-brake or press-brake bending process using straight bending dies. With a complex profile, the process is more like stamping without a die ring or binder. The difference in principle is that in Chain-die Forming the deformation is mostly concentrated to a few local areas in either bending or stretching/compression, instead of most of the material becoming deformed over a large area as in stamping.

In Chain-die Forming, the structure is as shown in Figure 4, the forming dies are machined on the die-blocks in accordance with the shape of a product. Die-blocks with the same axial thickness (pitch size) are stacked together during the machining, then the die-blocks are mounted on chain-links of a specially-made chain which has rollers running on the profiled track with a radius designed to simulate the working portion of a large roll. Generally, the roll radius simulated by the die-blocks is very large. For example, over 50 m corresponds to a deformation length of 0.5 m or more. The other part of the track should just be sufficient to close the chain into a loop. The new technique uses special chains as the carrying medium. The die-blocks are then mounted on the chains. Figure 3 shows the schematic diagram of Chain-die Forming.



(a) Schematic diagram of Chain-die Forming

(b) Strip at entry point of prototype

Figure 4. The schematic diagram of Chain-die Forming

A Chain-die Forming line is much like a roll forming line, as shown in Figure 5. The difference being that the roll former stands or passes are replaced by the Chain Former. Due to the fact that the capacity in each individual pass of Chain-die Forming is much higher than that of a roll forming pass, the number of passes required to form the same product is much less than in roll forming. Even though an individual Chain-die Forming stand is longer than a single roll forming stand, the total length of the line is shorter than a roll former. The other parts, driving system and control system, are identical to those in roll forming. This is the reason why Chain-die Forming could become the next generation of roll forming.

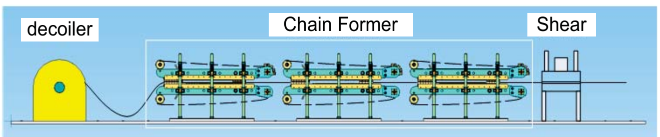


Figure 5. A typical Chain-die Forming line

III. Characteristics of Chain-die Forming

Chain-die Forming can be simply understood as roll forming using rolls with very large radii. With such large radii, the first contact point of roll and strip occurs much earlier and the length of the contact zone is much longer than in roll forming. With the increase of deformation length, the original complete deformation model gradually approaches to a simple air-brake bending model. Figure 6 shows a theoretical distribution of longitudinal strain to produce a 15 mm wide 15 mm high channel section by Chain-die Forming in a single pass. The maximum longitudinal strain of an edge point occurs at nearly the middle of forming length and is about 0.12% which is in an elastic regime. It is reasonable to believe that the formed channel has nearly zero residual stresses with such small membrane strain. To verify this opinion, a top-hat section is wire-cut along the transverse direction with two cuts and then along the longitudinal direction a few strips are also cut. Generally, if the top-hat were roll-formed, end-flare would occur and the longitudinal strips would curve immediately to release the residual stresses. As the top-hat is Chain-die Formed, as shown in Figure 7 the shapes along cuts do not have any observable variation.

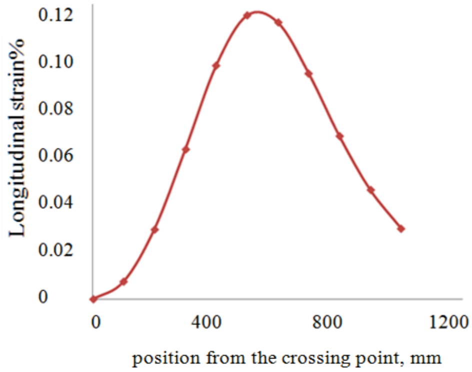


Figure 6. Longitudinal strain of an edge point

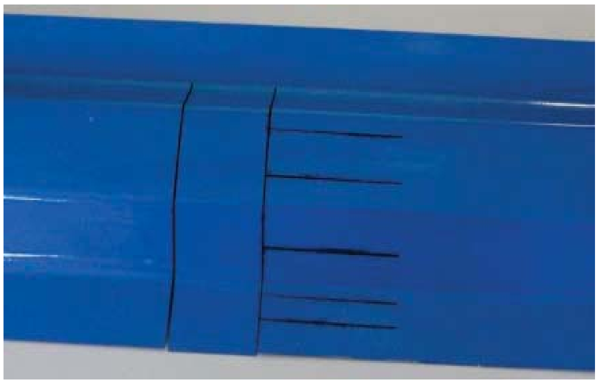


Figure 7. Wire-cut formed sample

As most of the redundant strain components are very small, under the limited elastic strain, the source causing most product defects in roll forming is thoroughly removed. The typical defects such as edge wave, end flare, twist, curvature, and so on are expected to no longer occur. With the improvement of the forming method, many limitations which must have been avoided in roll forming design such as hole position and groove depth are no longer there. Thus, Chain-die Forming is a much more flexible forming method than roll forming. Compared to conventional roll forming, some advantages of Chain-die Forming are:

Saving energy. The redundant strain components are dramatically reduced and the residual stresses and strains are almost completely removed. With the increase of the radii of the imaginary rolls, the forming distance can be increased significantly and the forming process approaches an air-brake bending process. As the sources of problems in roll forming are fully removed, the quality of the product and good to reject ratio can also be increased. The process is energy saving and the improvement of the quality of products and good to reject ratio can lead to the deduction of costs of a product and further save energy.

Simpler die design and fewer passes. As the forming distance is much longer than roll forming, in one forming pass more forming work can be completed in Chain-die Forming. In the flower pattern design, the key consideration is no longer how to control and distribute the forming angles in each pass, it concentrates on how to achieve the process compatibility between the Chain-die Forming passes. Thus, the design work can be significantly simplified and shortened, and the advantages of a smaller equipment footprint are also obvious.

Short period of tooling design and alignment. Because the forming process is more like an air-brake bending process, the tooling design can be produced by designing a pair of air-brake bending dies. When the alignment is completed, the chain-die block assembly can be removed anytime as the product is changed or re-assembled without new alignment. This makes the Chain-die Forming mill more capable and flexible, and saves the total capital of a factory making different similar sized products. This also gives more flexibility to the forming system in order to save material lost during realignment. The stock size and capital can also be minimized.

No slippage in forming direction. The imaginary radii are extremely large and within forming regime, the slippage between dies and strip is close to zero. This means there is less damage to materials with coating and painting, and the process is also suitable for the production of deep groove profiles. Therefore, the surface damage can be minimized, which is very important for materials with coating and painting. Also, the depth of the profile is no longer a problem as in roll forming.

Non-uniform profile products. Chain-die Forming can be applied to produce non-uniform profile products such as a conical tube. For those types of products, the dies are designed and machined to achieve the final shape in the process, in a fashion similar to a stamping die set. The discrete die-blocks are assembled to chain-links accordingly, and while the chain is moving, the corresponding opposite die-blocks move relative to each other in vertical direction as in a stamping process. Compared to the flexible roll forming under development in Germany and Japan, Chain-die Forming has the potential to lower the cost of equipment and achieve higher efficiency. It also has more potential than flexible roll forming in the automobile industry.

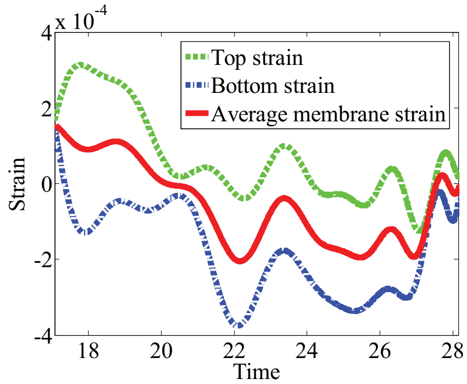
IV. Making Structural Parts of Motor Vehicles

A. Long and Straight Parts

Some of the structural parts of motor vehicle are straight with uniform profiles such as the bars under the seats. Generally these types of products can be roll formed and then cut to length. For UHSS, roll forming is no longer a sufficient way to produce these types of products because 1) the ends of the bar are not always a square shape and need to be pre-cut. The pre-cutting process is not preferred by roll forming engineers because of the end-flare phenomenon which can't be avoided; 2) mostly there are holes close to the edge or bend. Those holes will either be stretched to the point of losing its shape or even break the edge or tear off the bend; 3) the shape is normally asymmetrical which often causes twists after roll forming. The theoretical explanation is that residual stresses developed on both sides are asymmetrical; 4) difficult to straighten and compensate the springback.

Figure 8(a) shows a right-angled channel section sample Chain-die Formed by just one pass. On this sample, there are 3 holes located close to the edge (about 1 mm), close to the bend (1 mm) and across the bend. From observation and manually checking, there is no imperfection caused by the pre-cut holes, and also there is no endflare or twists and the web is perfectly flat. The strain gauge measurements at the edge point of the middle position show that the longitudinal strains are very small, thus corresponding to the theoretical prediction.

(a) holes close to edge and bend, and cross the bend



(b) strain gauge measurement shows a very low longitudinal strain

Figure 8. Chain-die Formed U-Channel

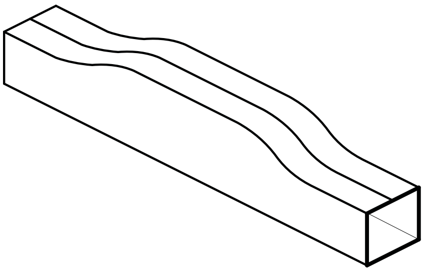
It should be pointed out that the strain gauge measurement results shown in Figure 8 do not follow the theoretical prediction shown in Figure 6 exactly. That is due to the noises from the forming machine. The longitudinal membrane strain measured is within ±0.02%, much smaller than the simple theoretical prediction, and shows that the simple theoretical prediction is conservative and that it can be used in future tooling design. During Chain-die forming there are many noise sources such as the transmission system, the motion of the dies and chains which can make lots of vibrations that would easily affect the shape of the strip. The strip oscillation leads to strain variation.

B. Producing Non-uniform Profile Products

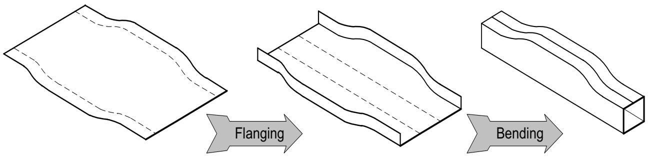
Because of the high strength and low elongation, the manufacturing process of many structural parts utilizing UHSS should be reconsidered and optimized. For example, the part shown in Figure 9(a) is a beam to make the chassis of a car

which is conventionally produced by blanking, roll forming, squashing, hydro-forming and finally trimming. Alternatively this tubular beam can be produced differently as shown in Figure 9(b). The question then becomes how to form a channel section with variable width as shown in Figure 10.

Intuitively the part shown in Figure 10 should be formed by stamping. When UHSS is employed, conventional stamping is no longer effective due to the high strength of steel and limited elongation. The high strength materials require more power and also lead to quick wearing out of tooling. Also, the cracks around the corner are due to the poor ductility of materials. A solution to overcome the limited elongation is to “bend” to shape instead of stamping, as in stamping there are large amounts of material deformation involved and using the “bending” the deformation of the product could be broken down to bend and tensile/compress occurring at different locations. This process can produce a product with very low plastic strain and therefore can be used to form materials with limited ductility.



(a) tubular beam in a motor vehicle



(b) modified process

Figure 9. A tubular beam of chassis

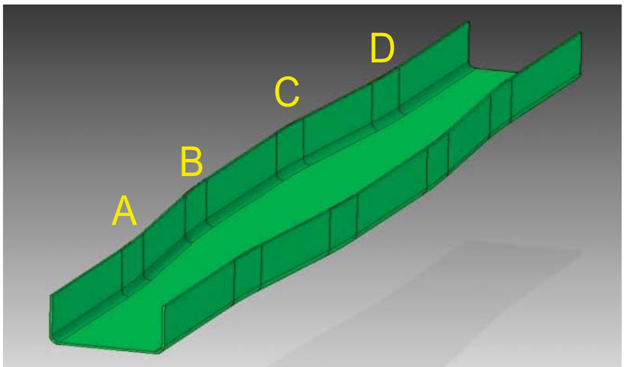


Figure 10. Typical structural part in a motor vehicle

Chain-die Forming is a forming process which implements such “bending”. The forming process is broken down into a few passes as shown in Figure 11. As shown in Figure 11, the final profile is gradually achieved by 3 passes and the forming die before slicing into blocks similar to the stamping dies. After assembling the forming mill, the blank is sent and deformed gradually in 3 passes continuously to the final shape. In such a forming process, the deformations mainly occur at these locations: bending deformation along bending lines, bend superpose on stretching at concave corner on flanges and bend superpose on compression at convex corners on flanges. Other straight portions of the channel remain straight without deformation. The maximum possible strains on those parts can be simply figured out using simple theory (as shown in Figure 12 red pulse shape curve), and it is far smaller than in the stamping process.

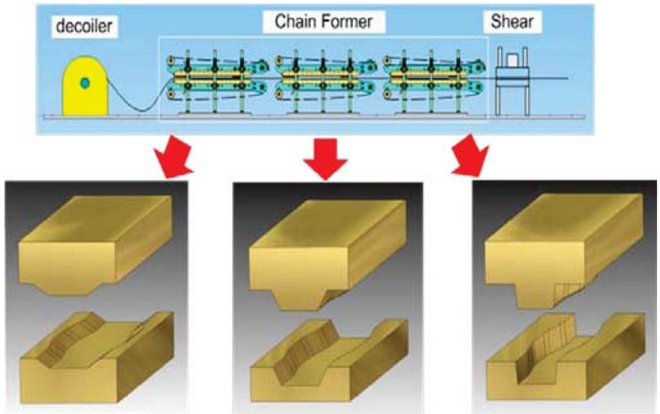


Figure 11. Chain-die Forming produce non-uniform profiles

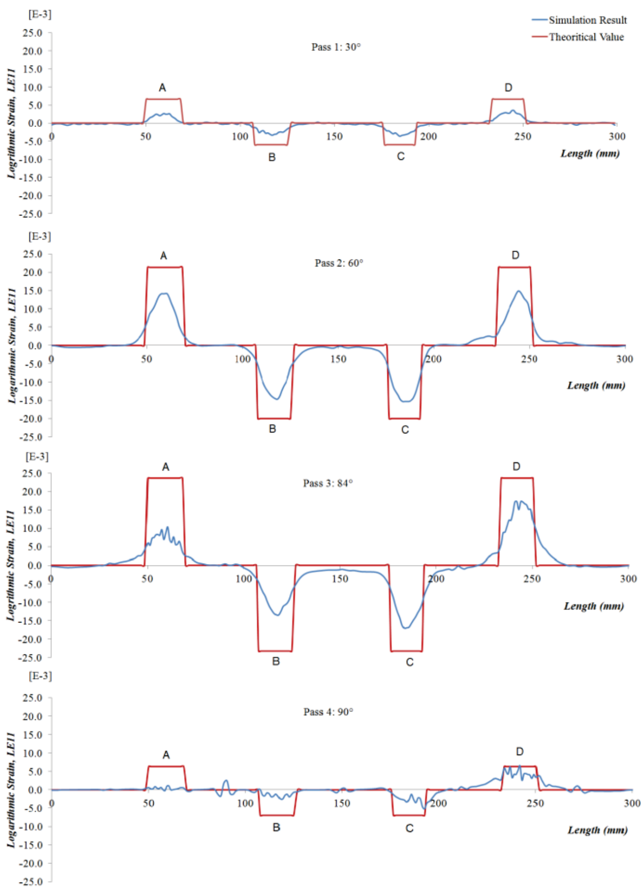


Figure 12. Theoritical strains alongthe edges and FEA simulation

FEA simulation has been processed on Chain-die Forming a product shown in Figure 10 [12]. There are four curved parts marked as *A* to *D* on the flange which need to be specially addressed and the maximum strain during forming needs to be investigated. The maximum longitudinal strains along the edge are plotted in Figure 12. All peak strains occur at near-middle points on the curves of the flanges and are smaller to the simple theoretical prediction. Also, accumulating all of the peak strains at each critical point, the total maximum longitudinal strain at the point interested is less than 3%. Therefore, the cracking observed from flexible roll forming will not occur in Chain-die Forming in this example. Also, from the simulated shape, no wrinkling is observed on the position which experienced compression.

C. Producing Thick Wall Products

During roll forming on, for example, a right-angled channel section, the flanges are normally deformed in a complex manner with bending superposes membrane stretching, reverse bending and membrane compression. The redundant plastic deformation on the flanges strain-hardens the flanges not only consumes lots of energy, but also causes product's defects. To roll form a thick gauge UHSS, the bending strains contribute a large portion of the effective strain on the surfaces. During roll forming, if the effective strain is larger than the elongation of UHSS, and because the roll forming is a continuous process, there will be many micro-cracks in the transverse direction on the surfaces of the flanges. Some of these cracks are visible but some of them are difficult to observe which will be a serious problem and endanger the safety of motor vehicles. As introduced previously, Chain-die Forming does not introduce any strain-hardening to the strip because the bending occurs over a long forming distance and it occurs much gentler than in roll forming. It will not develop any transverse cracks and also conserve the material's elongation to further process such as section bending.

V. CONCLUDING REMARKS

A new forming technology, Chain-die Forming, has been suggested to make UHSS structural parts of motor vehicles. Even though there is still no part produced by Chain-die Forming, the technology has the potential to solve the problems currently occurring in roll forming and stamping UHSS. What is required is government support and industrial involvement to ferment and push forward the new technology to industrial applications. It is expected to be applied widely throughout the automobile industry in the near future.

The new technology has the advantage of close to zero redundant strains during forming. All product defects caused by the complex deforming manner and redundant strains are not expected to occur. Therefore, the blanks can be pre-cut and then sent to fabricate the products. Some extra processes and techniques used in roll forming are no longer necessary such as tension between each pass, straightening, turkey-head correction, etc. The small redundant strains during forming result in zero residual stresses in the products. This is critical in product quality.

As the new method can be used as a continuous "stamping" process to "stamp" a product in a few stages, the process can be optimized to obtain an ideal strain distribution on a product. This is very difficult to do in stamping. Also, as the new method does not require a blank holder to hold the blank, the size of the blank is smaller than in stamping. This can improve the material's utilization ratio and reduce the cost.

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REFERENCES

[1] H.N. Han, C.S. Oh, G. Kim and O. Kwon, "Design method for TRIP-aided multiphase steel based on a microstructure-based modeling for transformation-induced plasticity and mechanically induced martensitic transformation", Materials Science and Engineering A, vol. 499, 2009, pp.462-468.

[2] K. Chung, K. Ahm, D.H. Yoo, K.H. Chung, M.H.Seo and S.H. Park, "Formability of TWIP (twinning induced plasticity) automotive sheets," International Journal of Plasticity, vol. 27, 2011, pp.52-81.

[3] S.A. Asgari, P.D. Hodgson, C. Yang and B.F. Rolfe, "Modeling of Advanced High Strength Steels with the realistic microstructure-strength relationships", Computational Materials Science, vol.45, 2009, pp.860-866.

[4] S.Oliver, T.B. Jones, and G. Fourlaris, "Dual phase versus TRIP strip steels: Microstructural changes as a consequence of quasi-static and dynamic yensile testing", Materials Characterization, vol.58, 2007, pp. 390-400.

[5] J.Hardell, E. Kassfeldt and B. Prakash, "Friction and wear behavior of high strength boron steel at elevated temperatures of up to 800°C", Wear, vol.264, 2008, pp.788-799.

[6] I. Mejia, A. Bedolla-Jacuinde, C. Maldonado, and J.M. Cabrera, "Hot ductility behavior of a low carbon advanced high strength steel (AHSS) microalloyed with boron", Materials Science and Engineering A, vol.528, 2011, pp.4468-4474.

[7] M.G. Lee, S.J. Kim and H.N. Han, "Finite element investigations for the role of transformation plasticity on springback in hot press forming process", Computational Materials Science, vol.47, 2009, pp.556-567.

[8] H. Karbasian and A.E. Tekkaya, "A review on hot stamping", Journal of Materials Processing Technology, vol.210, 2010, pp.2103-2118.

[9] E. Gülçeken, A. Abee, A.Sedlmaier and H.Livatyali, "Finite element simulation of flexible roll forming: A case study on variable width U channel", 4th International Conference and Exhibition on Design and Production of MACHINES and DIES/MOLDS, Cesme, TURKEY, 21-23 June, 2007.dm97.

[10] S. Ding, "Method and apparatus for forming the profile of deformable materials and deformable tubular sections", Australia Provisional Patent, PCT201090265, filled on 18 June, 2010.

[11] S. Ding, W.J.T. Daniel, J. Yuan and Y. Zhang, "Making roll forming flexible-Introduction to Chain-die Forming", Yokohama Tube & Pipe 2011 in Osaka, 2011, pp.341-346.

[12] J. Yuan, "Fundamental study of Chain-die Forming on making non-uniform profile products", Masters of Philosophy Degree Thesis, The University of Queensland, 2012.