The Developme ction Rolling Process for Strip

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Abstract

This research aims to examine the feasibility of a new concept in section rolling of thick strip, which either could not be rolled at present due to cracking at bent corners. Whereas, the second moment of area of sections could be increased through sharpened corners and increased gauge thickness. A heat assisted section rolling process is proposed. This process is based on application of high intensity heat on the inner surface of the strip, immediately prior to rolling. To investigate the new section rolling concept, the following work has been carried out.

Firstly, the material property of the S450 steel has been determined using the Gleeble simulator, followed by thermal conductivity tests. Since a freon was used to increase temperature gradient, the heat transfer coefficient for the freon-hot surface interaction was determined. Finally, the four point hot bending tests were conducted to validate the simulation model. For this purpose, a hot bending test rig was designed and fabricated, utilizing an halogen heater as the heat source. The results between experiment and simulation were compared and a good correlation was found.

Then, finite element analyses of a single pass hot rolling process has been adopted to investigate the neutral axis shift and section thickening effects. It is revealed that localised heating creates bulging on the compressed surface. The bulged surface affects the both neutral axis and thickening of the formed parts.

This research has demonstrated that localised heating has a potential to be employed in section rolling operations. It shows that the neutral axis of the bent region shifted closer to the tensile surface would reduce the tendency for surface cracking. In addition, the increase in thickness that arises at a bend would enhance the stiffness of rolled sections. Ultimately a process window for heat assisted section rolling has been established.

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Nomenclature

Latin Symbols, uppercase

A	The heated surface area (m^2)
A_c	Area of the emitting body (m^2)
Err	Error function
F	Force (N)
C_p	Specific heat (J/kg°C)
J	Conductivity matrix
L	Instantaneous length
Lo	Original length
Tx	Deformation length
D_d	Height difference between the two load points
E	Young's modulus (MPa)
G	Shear modulus (MPa)
Tz	Flange length
M_B	Applied bending moment per unit width during elastic loading
Q_{tot}	Total heat transfer
Q'	Input heat flux
Q_{max}	Maximum heat flux
Q_p	Heat generation due to the plastic work rate
Q_t	Internal flux vector
S	Shape function
$T_{a,b}$	Temperature of the points on the adjacent surfaces.
T_c	Cold surroundings absolute temperature (K)
T_h	Hot body absolute temperature (K)
T_∞	Ambient temperature (°C)
Tc	Calculated temperatures (°C)
T_m	measured temperatures (°C)
V	Vickers hardness
Q_{sup}	Generated power (W)
I	Current (Amp)

V	Voltage (Volt)
Iy	Second moment and
C_D^{-1}	Lumped capacitance matrix,
P	External force (N)

Latin Symbols, lowercase

a_1, a_2	Supporting points position.
d_c	Centre of deflection
f	Flexural rigidity
ŕ	Radial distance from the power source beam center,
r	Bending radius
k	The gap conductance
h	Heat transfer coefficient, sheet metal thicknesses
h,	Heat transfer coefficient for convection (W/(m^2 K)
p	Contact pressure
n_h	Power efficiency
q	Heat conductivity
q_c	Convection heat losses
q_r	Radiation heat losses
[illegible]	Heat flux vector
[illegible]	Maximum power output (W/m^2.sec)
[illegible]	Heat flux from the lamp filament of T_o
[illegible]	Heat flux received by a specimen at a temperature of T_n
[illegible]	Heat flux loss of heater system in W/m^2.sec
[illegible]	End-effects heat flux loss caused by heater design
k_n	Thermal conductivity normal to the surface (W/mK)
w	Heating band
t	Part thickness, heating time
v	Bending speed

Greek Symbols

β	Fraction of the plastic energy
λ	Isotropic heat conduction
σ	Stress (MPa)
υ	Poisson ratio
$\dot{\varepsilon}_{ij}$	Plastic strain rate
ε	Emissivity
ε_p	Plastic equivalent strain
ε_e	Engineering strain
ε_t	True strain
τ	Shear strain
σ	Stefan–Boltzmann constant for radiation (5.669 x10^{-8} ($W/m^2.K^4$)
ϕ	Interaction conductivity constant
θ	Bending angle
ρ	Curvature radius of the neutral axis
ρ_A, ρ_B,ρ_C	Bending curvature
γ	Heating concentration factor
ψ	deflection of the workpiece

Operators

Δ	Increment
∇	Divergence operator
Σ	Summations
$\partial(x)$	Dirac's delta function
$\frac{\partial f_{NA}(w,t,v)}{\partial w}$	Neutral axis sensitivity with respect to heating band
$\frac{\partial f_{NA}(w,t,v)}{\partial t}$	Neutral axis sensitivity with respect to heating time
$\frac{\partial f_{NA}(w,t,v)}{\partial v}$	Neutral axis sensitivity with respect to bending speed

$\frac{\partial f_{ST}(w,t,v)}{\partial w}$ Sectional thickening sensitivity with respect to heating band

$\frac{\partial f_{ST}(w,t,v)}{\partial t}$ Sectional thickening sensitivity with respect to heating time

$\frac{\partial f_{ST}(w,t,v)}{\partial v}$ Sectional thickening sensitivity with respect to bending speed

Abbreviations

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
BS	British Standard
BU	Buckling Mechanism
CRF	Cold Roll Forming
DIN	Deutsches Institut für Normung
FEM	Finite Element Method
HTC	Heat Transfer Coefficient
HASR	Heat assisted section rolling
JIS	Japanese Industrial Standards
LCS	Low Carbon Steel
TGM	Temperature Gradient Mechanism
UP	Upsetting Mechanism
2D	Two-dimensional
4PHBT	Four-point hot bending test

CHAPTER 1

RESEARCH MOTIVATION

1.1 Introduction

Sheet metal fabrication plays an important role in the manufacturing industry. It is extensively used to manufacture parts ranging from car body panel components to prismatic sections for structures in buildings. A variety of sheet metal technologies are available such as shearing, stamping, deep drawing, and incremental forming. One of them is cold roll forming, which is used to produce long and constant cross-sectional sheet metal products. This process is highly productive and versatile since certain operations such as punching, bending and welding can be included, resulting in ready-to-use products.

1.2 Current needs and their requirements

The quantity of cold roll formed and strip-based product is the third largest of all metal forming processes, world-wide. Industrially, this process is classified as 'cold-rolled sheet and sections' and based on the World Steel Association's report released in 2011, the total consumption of hot and cold rolled products reached 71.7 million tons in 2009. This volume consumes abcut 16% of the total steel consumption as can be seen in Figure 1.1.

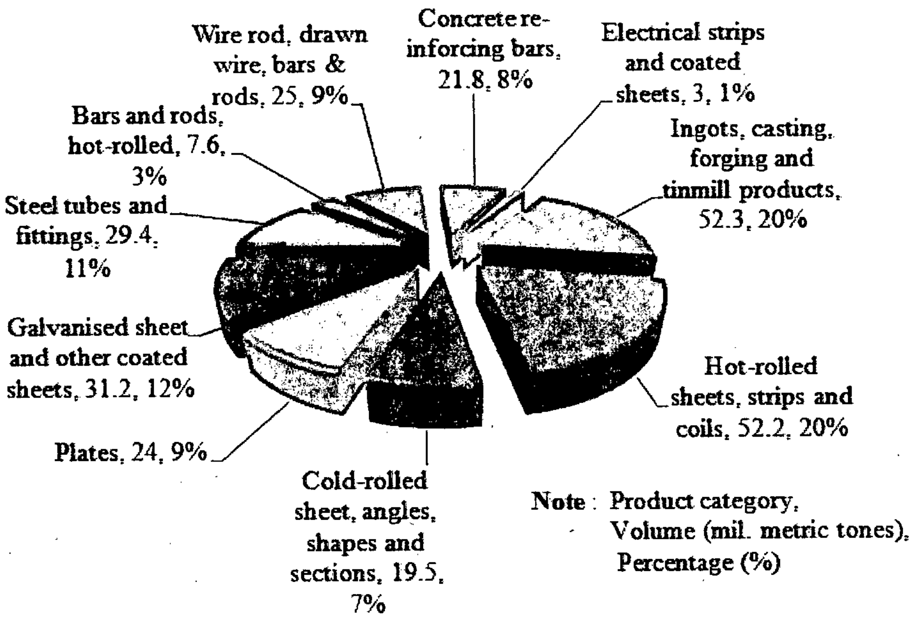

Figure 1.1: Steel production in year 2009 (World Steel Association, 2011).

1.3 Standards

All production activities in roll forming industries must comply with approved standards. By maintaining these, manufacturers are able to produce quality products that meet the customer needs and safety requirements. Moreover, implementations of the recognised standard in manufacturing activities are advantageous in terms of high productivity, low operating costs, and consistent product quality.

Standards applied to cold roll formed products are determined by the specific application and respective country's requirements. Selection of the standards depends on the specific requirements of particular regions of the world. For example, Table 1.1 shows standard designations to be used to produce certain products as parts for car bodies and household appliances. In implementing the new technology, the engineer or designer must make sure the final products comply with the standard requirements.

Table 1.1: Engineering standards related to cold roll formed products and processes

Quality standard	EN 10130/91	EN 10311/92	DIN 1623 T1/83	JIS G3141/90	BS 1449 Part 1/83	UNO 5866/77	ASTM A1008/03
Steel grades	Fe P01	DC 01	St 12	SPCC	CR SP 4	Fe P01	CS Type A
	Fe P03	DC 03	RR St 13	SPCD	SR SP 3	Fe P02	DS Type A
	Fe P04	DC 04	St 14	SPCEN	SR SP2	Fe P04	DDS

Besides the above, other types of standard are available for different types of product. For examples, standards specific to construction products are;

- BS 5950-1:2000 Structural use of steelwork in building. A Code of practice for a design of rolled and welded sections.
- BS EN 10111:2008 Continuously hot rolled low carbon steel sheets.

Nowadays, there are new structural Eurocode standards specifically established for the construction industry which were fully implemented in Europe in 2010.

1.4 Roll formed products

Roll formed products can be classified by the geometry of their cross-sectional profile. These can include; angle, channel or corrugated profile. With another categorization roll formed products can be classified as open, closed, pierced, and welded. Examples of roll formed products typifying the categories are shown in Figure 1.2.

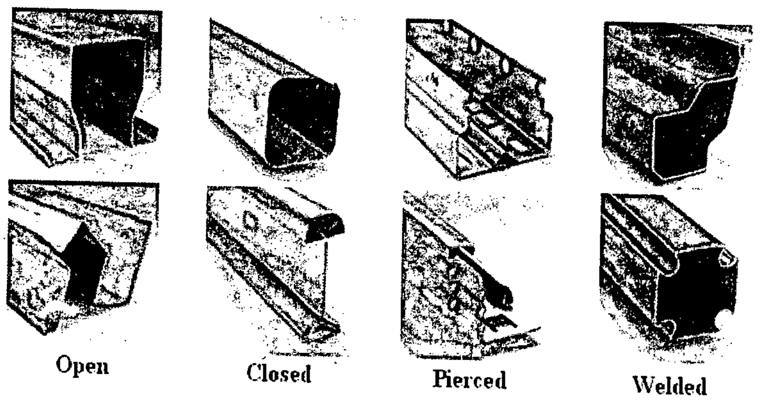

Figure 1.2: Roll formed products (Metsec, 2009).

Open profiles are products with a prominent gap between the two extreme edges of the sheet metal strip. In contrast, a closed profile has greater complexity and is distinguished by the minimal gap between the two extreme edges of the strip. Pierced profiles contain holes, punched through the strip during rolling. The fourth type, welded profiles represent more advanced products, in which roll formed edges have been joined using a continuous welding process during the roll forming process

Roll forming offers a number of distinct advantages over other metal fabricating methods. Among them are;

a) Products with a substantial high strength-to-weight ratio.
   Savings in weight may be as much as 30-50% compared to casting and bulk forming, leading to appreciable savings in cost of transport and installation. (Johnson, 1975).
b) High precision products.
   Roll-formed products can be manufactured to very accurate tolerances and good surface finish. The dimensional accuracy of final products typically is ±0.3mm tolerance (Yu et al., 2009).
c) Better part strength especially on the bending line.
   During a cold work process the yield and ultimate strengths will be increased, but metal ductility will be decreased (Cubberly, 1989).
d) Cheaper products.
   Cold roll forming is a high productivity process and high volume production results in low cost-per-piece. Also roll formed products contain up to 94% of their raw material, resulting in less scrap (Gulceken, 2007).

1.5 Applications of roll formed products

Various industries use roll-formed products, especially those engaged in engineering applications, such as;

- Construction-Structural sections, door frames, guide channels and shutter laths.
- Building- window frames, roofs, gutters and curtain wall sections.
- Automobile-Stiffeners, bumpers, chassis, door frames and panel sections.
- Aircraft-airframe stringers, helicopter blade leading edges, and jet engine seals.
- Appliances-Handles for ovens, drawer rails, trims, and structural beams.

- Furniture and fixtures- metal cabinets, shelves and display cases.
- Motorways and heavy construction- road signs, guard rails and piling

In the construction industry, most structural components are produced by cold roll forming including, floor decking, roofs and wall claddings. The wide area of application of roll forming products in this industry can be seen in Figure 1.3.

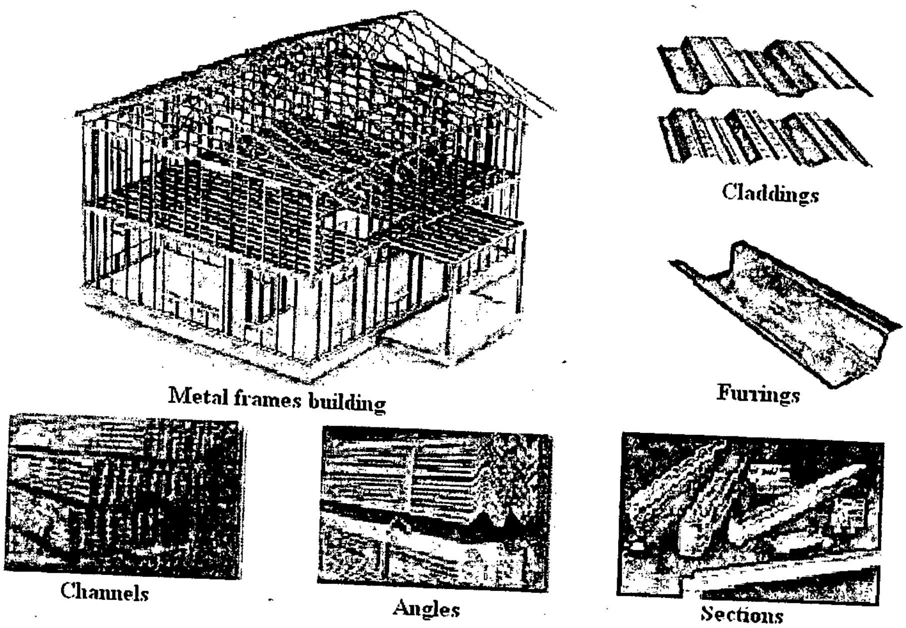

Figure 1.3: Application of roll formed products in construction (HighTechFinland, 2012).

Another important industry which uses cold rolled products is automotive manufacturing and the specific product applications can be seen in Figure 1.4. The automotive industry in particular has made extensive use of roll forming to produce body frames and trim, door headers, window guides, bumper reinforcements, seat tracks and door impact bars (Kevin & Ulrich, 2003).

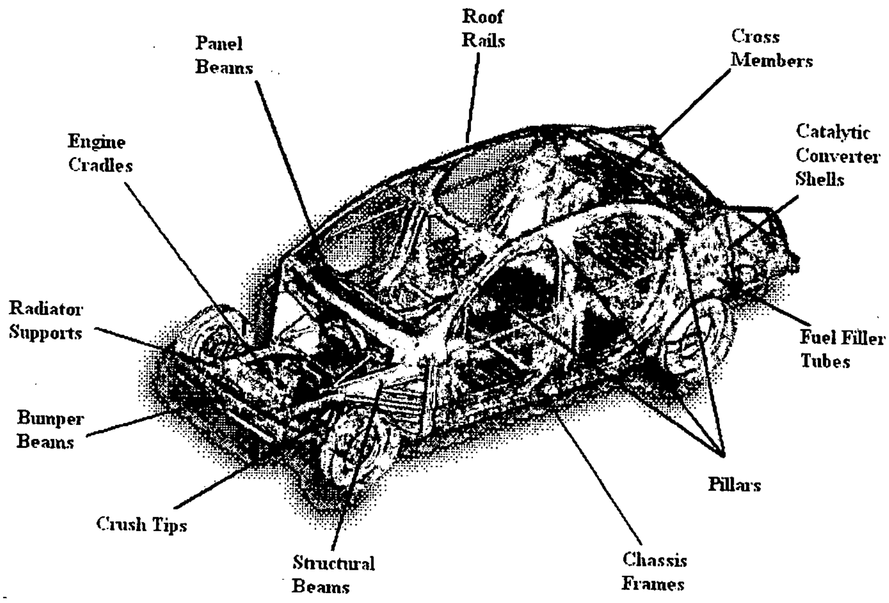

Figure 1.4: Application of roll formed products in automotive (Chubu, 2008).

In addition to the above-mentioned applications,, roll formed products are also important in other industries. For aerospace applications, roll formed products are used for window frames and helicopter blades (Ioannis, 2012). The domestic appliance industry also uses products such as handles, drawer slides; refrigerator shelves, ladder supports, and control panels (Lindgren, 2009). Further uses of these types of products can also be found in agriculture, transportation, and aerospace industry (Hisaki & Hiroshi, 2001).

1.6 Essential feature of the roll forming process

In industrial practice various types of roll forming machines, either conventional or customized designs are used. For a conventional roll forming machine, it consists of a wide steel base that supports the roll stations which are arranged in a single line. A set comprising top, bottom, and sometimes side rolls are fixed to each roll station. Basically, the main roll forming system consists of three sections; a raw material feeder, a series of stands for forming, and an additional process setup for punching and shearing. The typical arrangement of a roll forming line is shown in Figure 1.5.

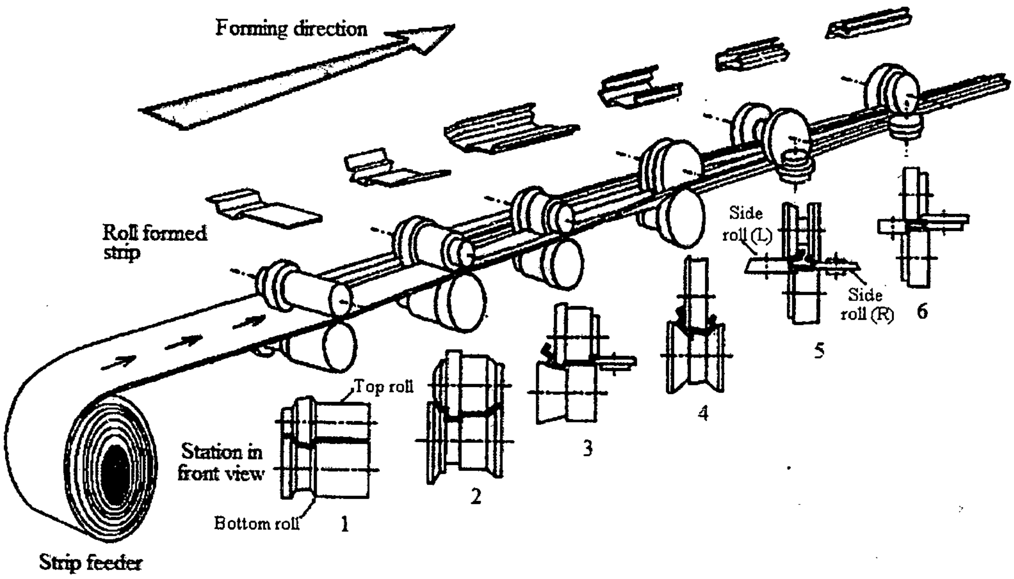

Figure 1.5: Typical set-up of a roll sequence to bend a section from flat strip (Sankar, 1996).

As shown in the above figure, the roll forming process begins with the strip feeder at one end of the production line. The metal strip is then unrolled and fed into a machine in the form of a flat strip. During production, the feeder speed plays a major role in maintaining consistent strip supply to the machine. Generally, the normal production rate for most roll forming processes is around 30 m/min, but there are machines which can run up to 100m/min (Sankar, 1996). The production rate depends greatly on the material thickness and the bend radius. It is also affected by shape complication and hence the number of stations, or steps required.

The number of roll stations required depends on section shape complexity, and their design has been largely a matter of skill and experience although nowadays computer-based expert systems and FE simulation software is available to aid a process planner. Figure 1.6 shows the development of a section shape through a series of rolls.

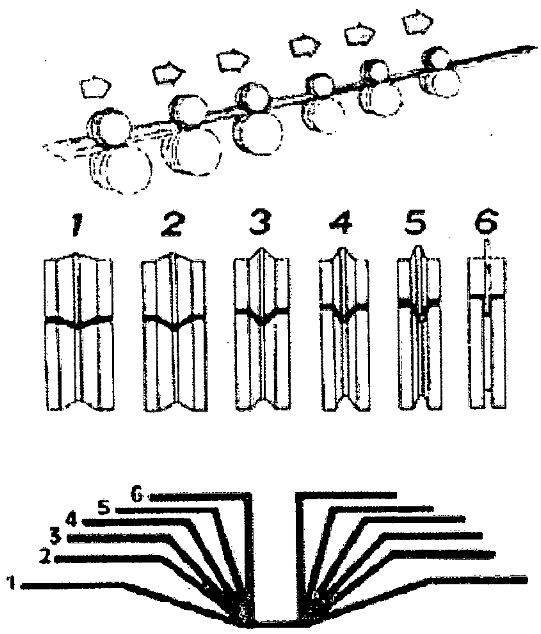

Figure 1.6: The strip is formed from an undeformed strip to a finished profile (Lindgren1, 2005).

Strip is fed into a roll forming machine, where it is rolled continuously using successive sets of rolls. Rollers are located on the respective station together with the rotating system. The number of roll stations is not fixed, but depends on the final product geometry and the material used. In each station, a set of top and bottom rolls are fixed to the stand with the option of side rolls on the left and right. The side rolls rotate on vertical axes, and are used for producing vertical surfaces on parts.

In addition to a continuous section, intermittent features are sometimes added to the product, such as holes and notches. Therefore, the roll forming machine can have operations before or after the roll stands, such as punching, stamping or shearing. With these additional operations, roll forming lines can be set up to punch and cut off parts continuously. Depending on process convenience, the roll forming lines can be set up to use a pre-cut die where a single blank runs through the roll mill, or a post-cut die where the profile is cut-off at the end of the roll forming process. A simple arrangement of a conventional roll forming system with the attached press and cut-off machine is shown in Figure 1.7.