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A Technology Roadmap for a Value Added Locally Processed Thin Steel Sheet to Suit Dietary Cans

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Abstract

Replacing imported industrial requirements by a locally processed products becomes an essential economical need to Egypt after the Russian-Ukrainian conflict. The current work investigates a successful locally processed industrial trial to replace imported IF- steel by locally processed ultra-low carbon steel for processing thin sheet suitable for dietary cans. The primary locally processed alloy is ultra-low carbon steel containing 0.04% C. The steel is continuously cast to compact slab processing (CSP) - direct hot rolling. Compact slabs usually enter a tunnel furnace for temperature homogenization, with an initial thickness 75mm, and followed directly to rough rolling with 34mm Thickness.

Numerical calculations would be executed to define the output thickness of each finish rolling stand to reduce 34mm slab thickness on a six stand roll mills to reach 2.5mm. A similar calculation is usually used for expecting the rolling temperature per each pass.

As a next step, Z- parameter for each pass is then calculated for tracing the grain size changes after each hot rolling pass. Calculations of the proposed industrial trial ensure that the proposed finish rolling pass design would lead to consecutive grain refinement reaching to 5μm. A cold rolling stage is executed to reduce sheet thickness from 2.5mm to 0.4mm. A physical simulation of cold rolling process is carried out by using cold upset on cylindrical specimens. The flow behavior of the compressed specimens identify three stage strain hardening rates. The intersection between 2nd and 3rd stages defines an essential need to intermediate annealing.

On the excessive cold rolling stage to < 0.4mm thickness, it is necessary to use cluster roll mill to secure thickness homogeneity and avoid rolling camber. A final annealing process could be executed to cope with the final request of the clients. The proposed technology roadmap summarizes processing stages that leads to a successful locally processed thin sheet steel suitable for dietary cans.

Keywords: Technology roadmap; Value added product; DRI pellets; CSP-direct hot rolling; Restricted deformation zone; Batch & continuous annealing; Locally processed thin steel sheet; Dietary cans

Introduction

The world crises after Covid-19 and Russian-Ukrainian conflict stroked most country economics. The destructive effects of the crises are more pronounced on the developing countries. Egypt is suffering strongly. As a consequence, it is planned to minimize importations and submit alternative solutions by replacing locally processed products to the market with standard specifications.

Egypt needs annually to 200 K. tones of imported thin steel sheets with 0.4-0.2mm thickness for dietary packing. The objective of the present work aims at constructing a technology roadmap for a value added locally processed thin steel sheet to suit dietary cans. The expected outcome of the current work is to establish processing routes for thin sheet ranging between 0.4-0.2mm thicknesses. The processed sheets have a variety of mechanical properties to suit its specific use.

Available Materials and Facilities

The main effective source of the primary material is the direct reduce iron (DRI) pellets. DRI does not contain copper (Cu), which is the prerequisite for cold rollability of the final steel sheet. Copper in steel alloys usually forms a brittle theta phase (θ- phase) at the ambient temperature of cold sheet metal forming.

The primary material of a successful industrial trail is ultra-low carbon steel alloy containing 0.053% C. Table 1 presents the chemical composition of the steel.

Table 1: Chemical composition of the steel.

Element	Chemical Composition					
	C	Si	Mn	P	S	Cu
%	0.053	0.052	0.177	0.012	0.009	0.049

Egypt owns two integrated units, which are using main DRI pellets as a primary material in electrical arc furnace melting in addition to the home scarp. Both units contain continuous casting for Compact Slab Processing (CSP), followed directly by consecutive roll mill stands for hot rolling to steel sheets. Alexandria national iron & steel company at Eldekhyla (ANSDK) is of one the existing units. ANSDK processes 52mm thickness slabs followed by a tunnel furnace for homogenizing the edges and bulk of slabs temperature at 1100°C. Five stands roll mills are directly following the tunnel furnace for the thickness reduction to 2.5 mm thickness [1]. The second unit was constructed at Ezz Flat Steel (EFS) Company, which is located at Ain EL- Sokhna- Suez. EFS has the same pervious technology as explain in ANSDK. However, EFS Company processes 75mm thickness slab. The factory provided with a rougher roll mill to reduce the slab thickness to 34mm. 6 stand roll mills are following the rougher [2]. Figure 1 presents schematically the Compact slab processing (CSP) followed by direct hot rolling at EFS Company.

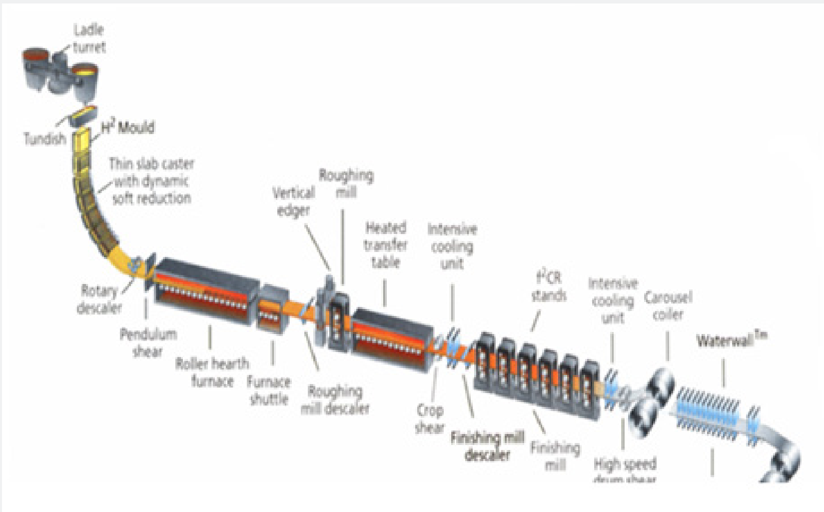

Figure 1: Continuous casting of compact slabs followed by direct hot rolling at EFS company.

Flat Hot Rolling Stage

On hot rolling, numerical calculations would be executed to define the output thickness of each finish rolling stand. EFS technical data are taken as a factory example to reduce 34mm roughed thickness on a six-stand finish rolling to reach 2.5mm final thickness. The after roughing conditions show a thickness (h_o) 34mm with a mean temperature (Tm) 1092°C and velocity (V_o) 1850mm/ sec. A power function trend is used to define output thickness for each pass. Figure 2 presents preliminary results to define strip thickness after each finish rolling stand. Figure 3 presents similar data processing for defining the expected temperature at each stand.

The next step is dealing with numerical calculations of the Z-parameter, which is the main feature that leads to the grain size changes after the hot rolling passes [3]. The austenite grain size after each hot rolling pass is defined as [4]

$$D = 535.4Z^{-0.1384}, \mu m \qquad [1]$$

Eq.1 indicates that the grain size is inversely proportional to the Z- parameter, i.e. high Z- parameter values means austenite grain refinement.

The activation energy of low carbon steel alloy is ranging between 276.12–287.56 kJ/mol [5]. In the current trail Q was taken as 280 KJ/mol. Table 2 contains the finish hot rolling data for 6- stands of the successful industrial trial.

The final results for calculation of the successful industrial trial ensure that the proposed finish rolling pass design would lead to consecutive grain refinement and reaching to 5μm at the last pass. However, we are looking for more confident processing conditions that leading to a dynamic recrystallization (DRX) phenomena. To achieve DRX phenomena, essential processing requirements would be executed. Thermomechanical simulation is considered

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as a confident process to summarize DRX parameters [6,7]. The main feature for gaining DRX during hot rolling appears as a peak on the hot deformation flow curve at specific conditions. Figure 4 demonstrates accurate tracing for DRX during processing of four hot rolling passes by using the physical simulation of thermomechanical processing [8]. However, the predefined condition for DRX could be shifted in some cases due to constrains to avoid processing in unstable deformation regions. Figure 5 shows the deformation maps of the steel under investigation defining the stable and unstable regions, [9].

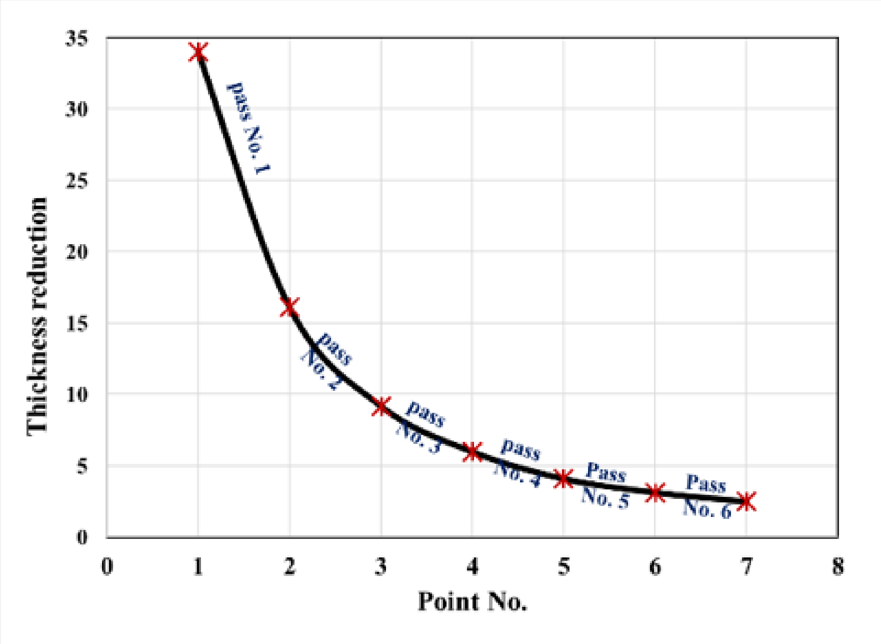

Figure 2: Thickness reduction/pass.

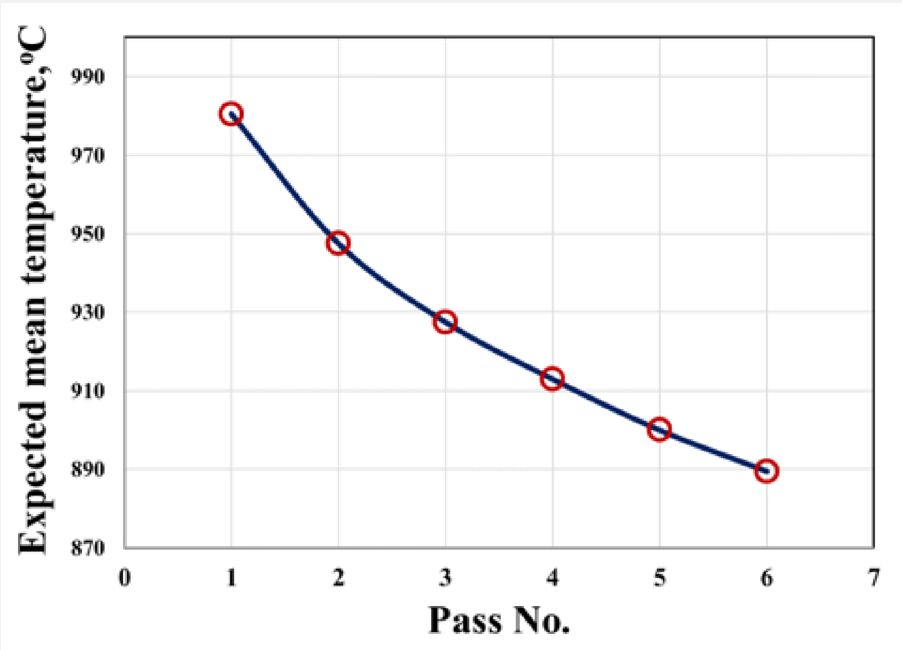

Figure 3: Mean rolling temperature/pass.

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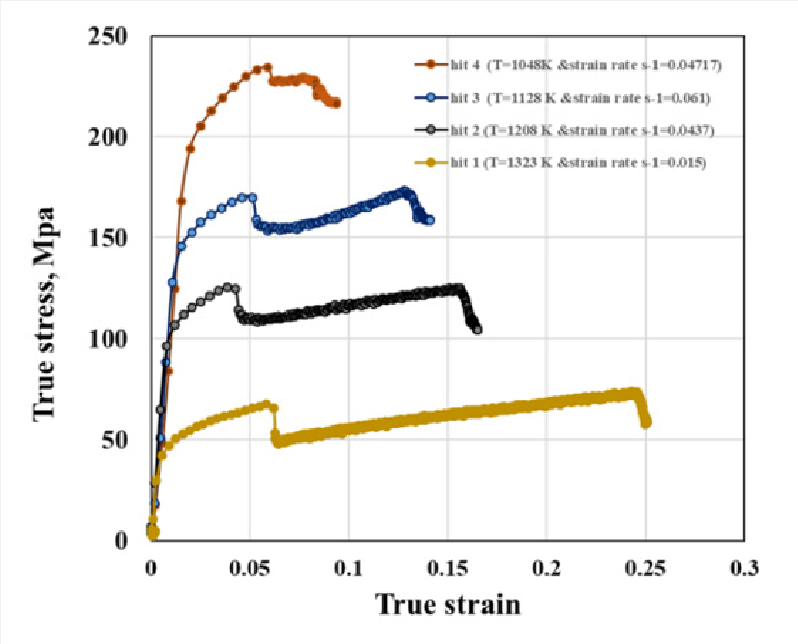

Figure 4: Tracing for DRX during processing of four hot rolling passes by using the physical simulation [8].

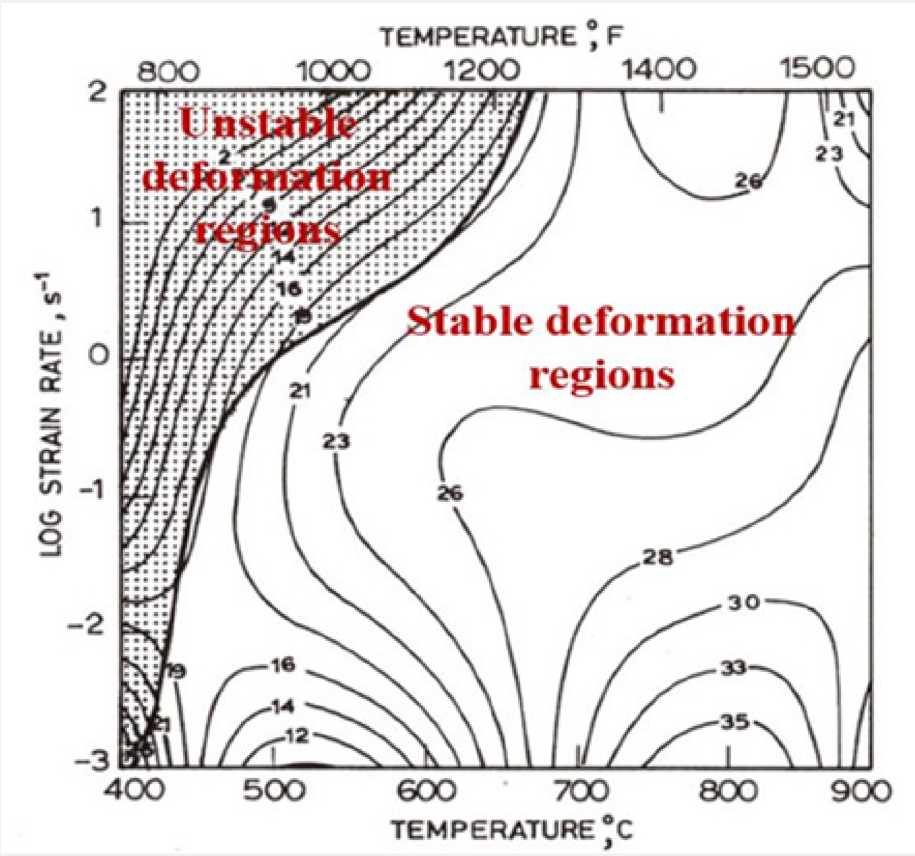

Figure 5: Deformation map of the steel under investigation defining the stable and unstable regions [9].

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Table 2: Finish hot rolling data for 6-stands of a successful industrial trial.

Pass #	Thick. In, h_1 mm	Thick. Out, h_2 mm	Strip Velocity, mm/s	Strain Rate ($\dot{\varepsilon}$), s^{-1}	Mean Temp., °C	Ln Z	Grain Size (D), μmm
1	34	16	1040	9.189	980.5	29.072	9.577
2	16	9.2	1740	18.573	947.5	30.502	7.858
3	9.2	6	2650	31.631	927.5	31.494	6.849
4	6	4.1	3700	53.252	913	32.358	6.078
5	4.1	3.1	4740	77.381	900	33.046	5.526
6	3.1	2.5	5770	95.951	889.5	33.520	5.175

Instability region could result in uneven microstructure homogeneity (duplex grain structure - banding) [10], as presented in figure 6. Deformation at unstable region can also result in edge flow localization figure 7a. Accumulative edge flow localization would lead to a worsening edge cracking figure 7b [11].

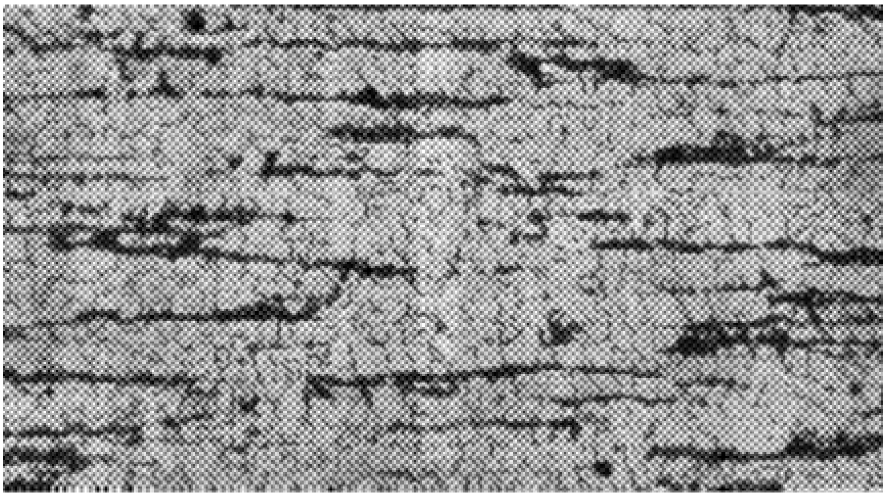

Figure 6: Uneven microstructure homogeneity (duplex grain structure- banding).

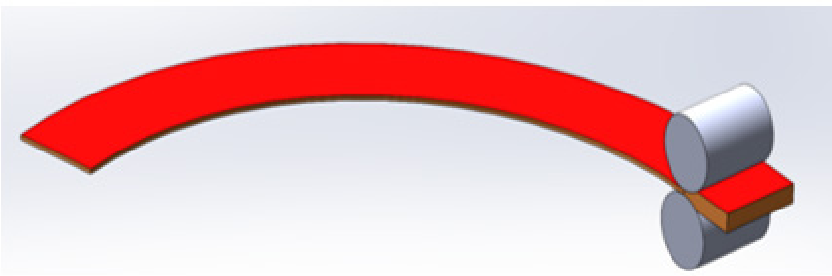

Figure 7a: Flow localization.

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Figure 7b: Edge cracking, [11].

Cold Rolling Stage

Cold forming processes are extensively dealing with thickness reduction and dimensional accuracy. It is beneficial to start with a simulation process to define parameters for the cold rolling.

Cold upsetting test is consider as a useful precise tool for simulation of cold rolling. The upsetting test results in compressive stress-specimen height presenting flow curve. A cylindrical test specimen with a height equals 1.5 the diameter is consider as a favorable compression test specimen. Figure 8 presents the flow stress against specimen height, which prevails three identified strain hardening rate stages. The 1st stage shows low strain hardening rate reflecting easy deformation behavior. The 2nd stage presents intermediate strain hardening rate, while the last stage reveals excessive strain hardening rate. The point of intersection between the intermediate and final strain hardening rates is usually taken as necessitate for intermediate annealing to avoid worsening of sheet edge cracking. Intermediate annealing is usually executed at temperature less than Ac1, where there is no metallurgical changes happened.

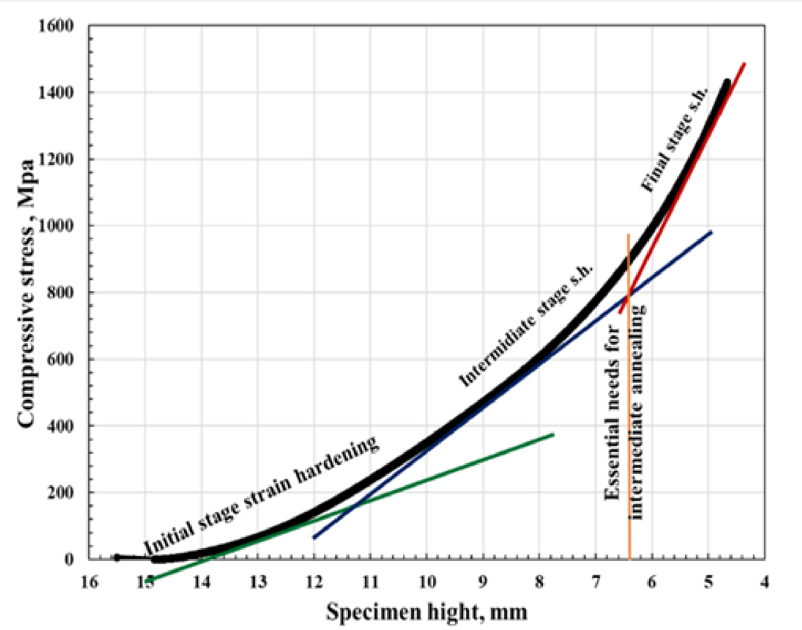

Figure 8: Flow stress against specimen height during upset proceeding.

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Figure 9 presents a macro-structure of 3D cross sectional model for cold upset deformed specimens. The whole cross section could be divided into two different areas. One of them represents a restricted deformation area (upper and lower conical areas), while the other represents a free deformation area (core sector area). The conical areas are surrounded by a narrow band, which is called adiabatic shear band (ASB). ASB has severe deformed grains where the original equiaxed grain morphology was no longer visible. The grains of ASB are completely elongated into fibrous microstructures (known as shear bands). The restricted deformation areas have very small plastic deformations due to the friction resistance between upsetting tool and specimen surfaces. Consequently, these parts could be regarded as rigid zones [12].

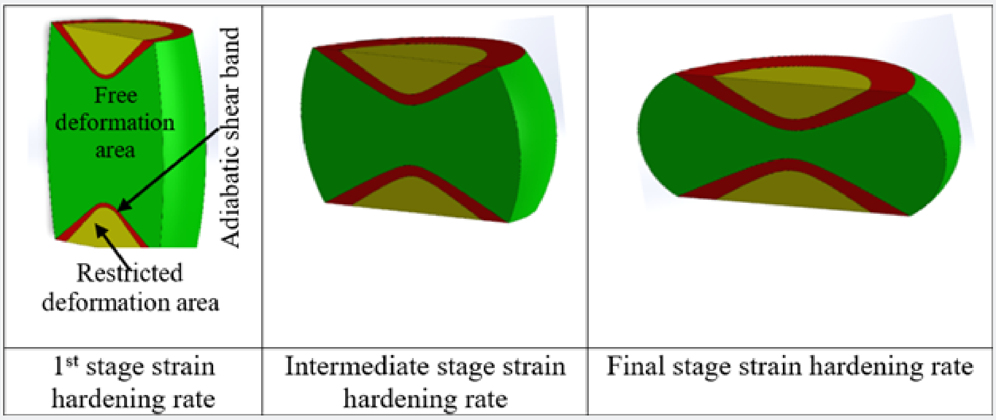

Figure 9: Macrostructure of 3D cross- section model for cold upset deformed specimens.

It can be concluded that the gap between the restricted cones is decrease by proceeding the upset test. By time the state of strain hardening changes from a stage to the other as presented in Figure 9, where a tighten zone is created between the head of conical restricted areas.

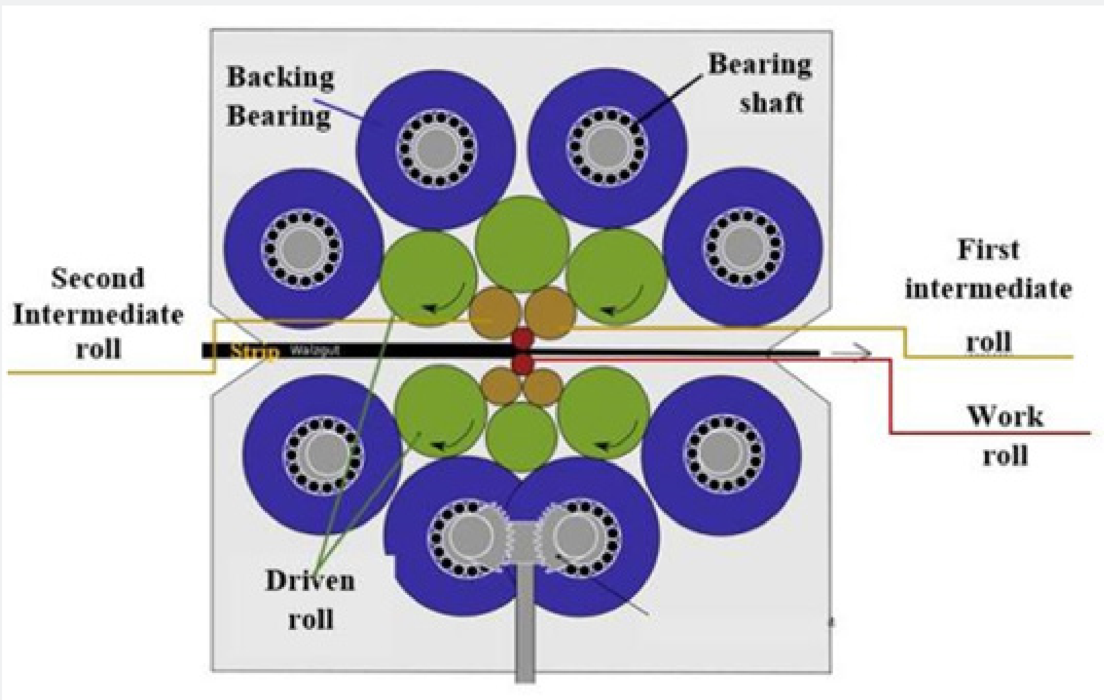

Figure 10: Construction of sendzimir cluster roll mill [13].

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Roll mills should be modify to continue successful homogeneous thickness reduction of sheets. Sendzimir cluster roll mill is one of the developed and modified mills [13], where it contains bearing, driven, intermediate, working rolls sequence, as presented in figure 10. Cluster roll mills reduce or even vanish the camber that results during last rolling passes increasing profitability of thin cold rolled sheets.

Customers request broad variates of dietary cans, which can be satisfied by different thin sheet state. Some cans are processed of full hard thin sheet. However, in some other cases, cans manufacturing steps may need to some ductility which reflect the necessity for ductile or semi ductile annealed thin sheets. Semi ductile sheets would be subjected to stress relief annealing at a temperature < Ac1. Moreover, ductile sheets would be subjected to process annealing at a temperature >Ac1.

Annealing process would be either batch annealing or continuous annealing [14]. It is highly preferred to used continuous annealing especially with thin thickness sheets (<0.4 mm thickness) to avoid damage of sheet edges and lessen staking when temperature becomes higher than Ac1 at the processing annealing.

Conclusion

Calculated finish hot rolling parameters were leading to a consecutive grain refinement. Simulation by Cold upset results in three stages strain hardening rates. Intersection between 2nd and 3rd stages defines an essential need to intermediate annealing.

On the cold rolling stage, excessive thickness reduction (< 0.4mm thickness) necessitates cluster roll mill to secure thickness homogeneity and avoid rolling camber. The proposed technology roadmap summarizes processing stages that leads to successful locally processed thin sheet steel suitable for dietary cans.

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