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EXPERIMENTAL ANALYSIS OF THE ALUMINUM COLD ROLLING PRODUCTION PROCESS: A CASE STUDY ON THE 1050 H0 ALLOY

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Abstract. The paper deals with the investigation of the production process of aluminum and delves into the intricate technological production chain associated with aluminum, with a specific focus on the crucial cold rolling process utilized in the fabrication of aluminum coils. Using rigorous experimental analysis, the study thoroughly evaluates the distinct stages involved in the cold rolling procedure, giving particular attention to the esteemed and distinctive 1050 alloy of aluminum. The study thoroughly addresses the process of achieving the desired mechanical properties of aluminum, encompassing both theoretical and experimental investigations. First, a theoretical framework is established to understand the underlying principles governing the chemical and physical properties of aluminum. The laboratory analysis focuses on the main technological advancements involved in the hot rolling process of an aluminum coil with dimensions measuring 6.60*1660 mm. The objective of this process is to achieve conformity with the 0.30*1500 mm H0 standard. The mechanical properties of a material obtained through experimental part involving metal cold rolling and thermal processing processes are as follows: a tensile strength (Rm) of 84 MPa, a yield strength (Rp) of 42 MPa, and an elongation of 28%. The material composition consists of 99.59% Al, 0.223% Fe, 0.128% Si, and 0.059% other trace elements. The meticulous research conducted significantly contributes to the current understanding of the aluminum cold rolling production process.

Keywords: *Aluminum, production, cold rolling, aluminum production process, technology, 1050 alloy*.

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1. Introduction

Aluminum coils represent indispensable components across a diverse array of sectors, including construction, automotive, aerospace, electrical, and packaging industries. This indispensability stems from the exceptional attributes inherent in aluminum, such as its low density, superior conductivity, corrosion resistance, and remarkable formability. The production of high-quality aluminum coils necessitates a meticulously orchestrated series of steps, wherein each step assumes a pivotal role in the realization of the desired properties and performance characteristics.

The process of hot rolling plays a vital role in the production of aluminum coils. This phase involves the conversion of aluminum alloys, initially stored in furnaces, into coils of predetermined thicknesses, typically falling within the range of 6 to 8 mm. During

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this process, precise quantities of additional alloying elements are introduced to the pure aluminum alloy, as determined through meticulous laboratory analyses. The liquid aluminum is carefully rolled into large coils at a controlled, slow speed, resulting in coils weighing approximately 10 tons. Typically, the hot rolling process employs a 2-shaft system, wherein the molten aluminum is solidified and shaped into coils within the rolling system, following procedures that adhere to stringent measurement standards.

Following that, the essential cold rolling process is employed as a subsequent stage in aluminum production. The coils acquired from the hot rolling workshop undergo rapid rolling at low temperatures to attain diverse thicknesses, typically ranging from 8 mm to 0.15 mm, in accordance with specific customer specifications and needs. Similar to the hot rolling process, cold rolling predominantly utilizes a 2-shaft system. The essence of this technological process lies in subjecting the aluminum coils to physical deformation under cold conditions, giving rise to the moniker "pressure mills" for cold rolling mills. Within this process, the coil experiences deformation and thinning between aluminum shafts, subjected to compressive loads exceeding 1,000 tons. The traction force exerted by the opening and winding shafts assumes a vital role in this process. Conceptually, the aluminum metal undergoes longitudinal stretching analogous to the stretching of chewing gum. The absence of friction and heating during the spreading of the aluminum coils in the cold state ensures a surface characterized by smoothness and transparency. Facilitating this process, a coolant oil containing kerosene is employed, exerting high-pressure to aid in the smooth spreading of the coils. This high-pressure coolant oil not only enhances the smoothness and transparency of the coil surface but also facilitates effective cooling, maintaining optimal temperature conditions during the process.

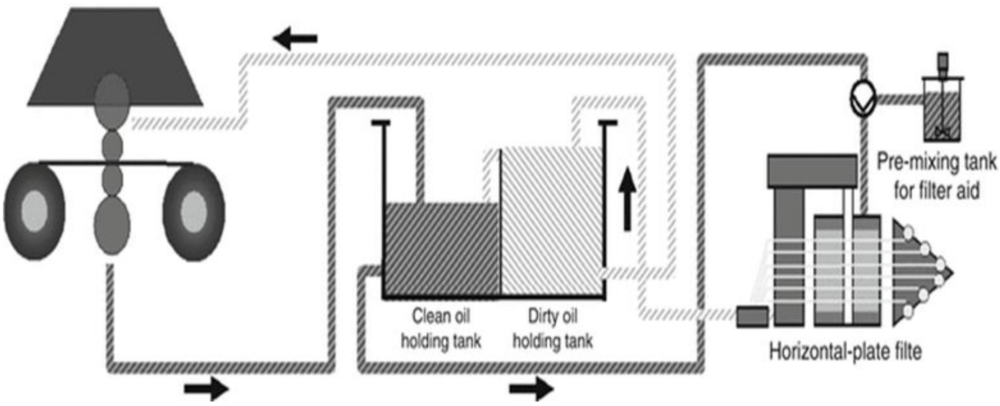

Fig. 1. Cold rolling process. From left to right: Cold rolling machine – Kerosene coolant dirty and clean oil tanks – Filtration
Source: Karhausen & Seiferth (2014)

The production of semi-finished aluminum products predominantly involves the utilization of roll sheets with diverse geometric dimensions. Aluminum coils find extensive applications across industries ranging from construction and transportation to food and electronics. Aluminum coils are categorized into different alloy series based on their chemical composition. By combining aluminum with various metals, a material with enhanced rigidity, flexibility, durability, and strength is achieved. Each alloy series represents a base of aluminum blended with specific metal components. In general, there are variations in the composition of other metals within each series, with the quantity decreasing.

The pioneering contributions of German metallurgist A. Wilm are widely acknowledged as transformative in the realm of aluminum alloys. Prior to his work, aluminum alloys exhibited limited strength and corrosion resistance (Chemello *et al*, 2014). Wilm made a groundbreaking discovery regarding a natural wear phenomenon that significantly improved the strength properties of aluminum alloys. The creation of aluminum alloys entailed the incorporation of precise percentages of other metals, primarily magnesium, manganese, copper, iron, and others. The amalgamation of different metallic elements yielded distinct grades of aluminum, each assigned a unique name in accordance with numerical coding. Over time, advancements in aluminum technology have been realized. Extensive research conducted in both industrial and scientific laboratory settings has led to the implementation of novel methodologies. Consequently, new aluminum grades with distinct characteristics, production techniques, and physico-chemical properties have been developed. The pursuit of new alternatives, technologies, and discoveries for aluminum alloys remains an ongoing endeavor, with continuous exploration aimed at expanding the possibilities in this field.

Table 1. Aluminum alloys

1xxx (1050, 1070, 1080, 1100, 1200 ...)	99%(+) Aluminum
2xxx (2004, 2014, 2020, 2024, 2036 ...)	Aluminum + Copper
3xxx (3003, 3004, 3005, 3102, 3105 ...)	Aluminum + Manganese
4xxx (4006, 4007, 4015, 4032, 4043 ...)	Aluminum + Silicon
5xxx (5005, 5050, 5052, 5083, 5182...)	Aluminum + Magnesium
6xxx (6005, 6010, 6060, 6061, 6066 ...)	Aluminum + Magnesium- Silicon
7xxx (7005, 7010, 7034, 7072, 7075 ...)	Aluminum + Zinc
8xxx (8006, 8009, 8011, 8030, 8091 ...)	Aluminum + Ferrum- Silicon Litium etc.

The 9xxx series offers immense potential for the exploration of novel alloy inventions and innovations. The mechanical properties of each aluminum series are governed by its distinctive chemical composition. Every individual aluminum alloy brand possesses its own specific chemical and physical characteristics, tailored to suit diverse industrial sectors. The selection of a particular brand of aluminum is contingent upon meeting specific application requirements, while considering designated end-use destinations and appropriate processing conditions. Moreover, aluminum alloys are categorized into non-heat treatable and heat treatable types, based on their respective production processes. The fundamental differentiation between aluminum non-heat treatment and heat treatment resides in the implementation of controlled thermal manipulation and cooling procedures. Non-heat treatment entails the manipulation or formation of aluminum without inducing substantial alterations to its microstructure, primarily impacting its mechanical properties. Conversely, heat treatment employs precise temperature regimes and regulated cooling to induce structural modifications within the material, yielding desirable enhancements in its mechanical properties. New and existing applications, such as foil and structural plate, have witnessed the development of high-performance non-heat treatable alloys. These alloys are specifically engineered to possess superior properties and meet the diverse requirements of various industries (Sanders *et al.,* 2004).

Table 2. Classification of aluminum alloys

Alloys	**Process**	**Tensile Strength**
1xxx	Non-heat treatable	70 - 175 MPa
2xxx	Heat treatable	170 - 520 MPa
3xxx	Non-heat treatable	140 – 280 MPa
4xxx	Non-heat treatable	105 – 350 MPa
5xxx	Non-heat treatable	140 – 380 MPa
6xxx	Heat treatable	150 – 380 MPa
7xxx	Heat treatable	380 – 620 MPa
8xxx	Heat treatable	125 – 560 Mpa

The "H temper" in aluminum production refers to the temper designation system used to classify the mechanical properties of aluminum alloys. It signifies the specific heat treatment processes undergone by the alloy, which affect its final properties. The temper designation consists of a numerical code followed by the letter "H" and another number, indicating the level of hardness achieved. Higher numbers indicate greater hardness resulting from more extensive heat treatment. Alloy 1050 is classified as a commercially pure aluminum alloy within the 1xxx series. It is renowned for its notable resistance to corrosion, high thermal and electrical conductivity, and favorable formability. Concerning the mechanical properties in H tempers, alloy 1050 typically demonstrates lower strength in comparison to alloys containing alloying elements (Anderson *et al.,* 2019). The available H tempers for aluminum alloy 1050 encompass HO, H12, H14, H16, H18, and H22, H24, H26 which indicate varying degrees of work hardening and subsequent strength levels achieved through heat treatment. Generally, higher H numbers are indicative of increased hardness and strength within the alloy.

The aluminum production process involves systematic experimental analyses that are routinely monitored throughout the various technological stages. Similar to the production of other metals and materials, it is not uncommon to encounter unexpected deviations and variations in the mechanical indicators of aluminum. Hence, the purpose of continuous practical experiments is to address and rectify these issues. It is important to note that even with identical chemical compositions and physical parameters, it is not guaranteed to obtain identical results in different experimental settings. This can be attributed to subtle differences in chemical composition at the micro level, minor variations in physical strength and tensile strength, variances in thermal processing conditions, as well as slight discrepancies in parameter adjustments made by operators. The overarching objective of the experimental research study is to attain a satisfactory average result, considering these inherent disparities and potential sources of variation.

2. Material and Methods

The most extensive literature pertaining to the theoretical underpinnings of aluminum metallurgy comprises a significant compilation of articles edited by Lumley (2011). This compilation delves into the fundamental aspects of aluminum industry technologies, encompassing the mining sector as well as the latest advancements in fabrication processes. Another noteworthy example of comprehensive literature is the multi-article book authored by Totten and MacKenzie (2003), which extensively explores the physical production processes of aluminum, ranging from rolling technologies to annealing procedures. Huynh et al. (2019) conducted an extensive experimental study aiming to thoroughly examine the distributions of mechanical properties and residual stresses across the cross-sections of cold-rolled aluminum. Hajizadeh et al. (2020) undertook a comprehensive comparison to examine the microstructure and mechanical properties of 1050 aluminum when exposed to the combined processes of constrained groove pressing and cold rolling. In Sidor et al. (2021) investigated the gradual alterations in dislocation density within a cold-rolled 1050 aluminum alloy. To characterize the deformed state, the researchers employed various techniques, including numerical approaches, indentation techniques, X-ray diffraction line profile analysis, and electron backscattering diffraction. Bátorfi et al. (2023) conducted a study with the objective of evaluating the deformation behavior of a particular aluminum alloy, specifically 1050, through the incorporation of constitutive model parameters.

The technological process flow of aluminum coil production consists of the following main stages:

- Casting and hot rolling;
- Cold rolling;
- Annealing;
- Final quality requirements.

Continuous casting, the prevalent method employed, entails the utilization of water-cooled rollers to solidify the molten aluminum into uninterrupted and elongated strips. This technique facilitates the production of aluminum coils characterized by consistent dimensions and desired alloy compositions. Hot rolling occupies a critical stage within the aluminum coil production process. The cast aluminum strips undergo reheating and subsequently traverse a series of rolling mills. This progressive operation reduces the strip's thickness and refines its microstructure, thereby engendering improved mechanical properties and surface finish. The precise control of temperature, rolling speed, and pressure during hot rolling ensures the attainment of the prescribed coil thickness and uniformity.

Following hot rolling, the aluminum strip undergoes further processing through the cold rolling phase. This particular step encompasses the passage of the strip through a sequential arrangement of rolling mills, all conducted at ambient temperature, with the overarching objective of achieving the desired thickness and enhancing the material's mechanical attributes. Cold rolling imparts heightened strength, superior surface finish, and narrower dimensional tolerances to the resultant aluminum coils.

In order to bolster the coil's formability and alleviate the internal stresses arising from cold rolling, the application of an annealing process is deemed necessary. During this phase, the aluminum strip is subjected to meticulously controlled heating and cooling cycles, thereby refining its microstructural characteristics, diminishing its hardness, and enhancing its ductility. The annealing process further contributes to the attainment of the desired coil flatness and surface quality.

The fulfillment of the ultimate quality requirements necessitates the incorporation of a myriad of processes, namely tension leveling, trimming, slitting, cleaning, washing, and packaging. These individual procedures are of paramount importance in ensuring the compliance of the aluminum products with the predefined standards and specifications. Tension leveling, for instance, serves to eliminate any residual stresses present in the material, thereby enhancing its overall flatness. Simultaneously, the execution of trimming and slitting operations facilitates the attainment of the desired dimensions and widths for the aluminum products. Moreover, meticulous cleaning and washing protocols are scrupulously implemented, thereby effectively eliminating any surface impurities or contaminants and guaranteeing an immaculate surface. Finally, the utilization of appropriate packaging techniques is considered indispensable for the purpose of safeguarding the aluminum products throughout their transportation and storage phases.

3. Research Findings

3.1. Chemical Composition and Technical Requirements of 1050 Alloy

Following the primary production phase of aluminum, subsequent stages are conducted in accordance with prevailing market demands. These subsequent processes aim to transform liquid aluminum into ingots and coils. The electrolysis method yields pure aluminum, which is further classified into various alloys and subjected to compositional modifications to broaden its industrial applicability. Chemical additives are introduced, and minute quantities of other metals are incorporated depending on the specific alloy type. For instance, aluminum coils belonging to the 1050 alloy are categorized within the 1st series of alloy types. This particular alloy type is comparatively softer, as it contains fewer hard metal additives, consisting primarily of over 99% pure aluminum. Each aluminum alloy series possesses a distinctive chemical composition, and this classification system adheres to established standards within the international business milieu.

Table 3. Chemical composition of 1050 alloy series aluminum

Al	**Fe**	**Si**	**Mn**	**Zn**	**Cu**	**Mg**	**V**	**Ti**
99.5-99.6%	0-0.4%	0-0.25%	0-0.05%	0-0.05%	0-0.05%	0-0.05%	0-0.05%	0-0.03%

Source: MakeItFrom (2020).

The 1050 alloy aluminum type, produced as a semi-finished product through the cold rolling technological process, necessitates adherence to specific technical requirements. In terms of production classification, aluminum commodity falls under the common strip category. A cold rolling machine is utilized to process an aluminum coil, measuring approximately 6.60 x 1660 mm and weighing around 10 tons, which has undergone prior treatment in the heating technological process. The objective is to attain the prescribed specifications of 1050-H0, with dimensions of 0.30 x 1500 mm.

Table 4. Technical Requirements of 1050 alloy

Product	Alloy series	Status	Incoming material	Finished product	Quality requirements
Common strip	1050	H0	6.60 x 1660 mm	0.30 x 1500 mm	GB/T3880 - 2006

3.2. Experimental Flow of the Production Process

Prior to initiating the rolling process, it is imperative to conduct a luminousness assessment of the oil to ensure it exceeds 85%. The oil used must exhibit a non-light tight property, devoid of any suspended particles visible to the naked eye. Failure to meet these criteria will impede the commencement of production. Moreover, for the rolling operation, the temperature of the rolling oil should be maintained at a minimum of 30°C, while the oil pressure must reach a minimum threshold of 0.4 MPa. These requirements are essential for ensuring the optimal conditions necessary for successful rolling.

The production process follows a sequential flow consisting of two main stages, namely deformation and annealing, which are conducted to achieve specific physical characteristics required for the aluminum coils. During the deformation stage, the metal undergoes compression and tension, resulting in thinning of the aluminum strip and an increase in its mechanical stiffness. If the deformation percentage exceeds the prescribed limits for the increase in mpa indicators, an annealing process becomes necessary in subsequent passes. Annealing is a thermal treatment process in which the hardened metal is softened at a specific temperature. Through recrystallization, the microstructure of aluminum expands, providing the required flexibility for subsequent deformations. The annealing process also plays a vital role in achieving the desired H values. The degree of annealing is determined based on factors such as the chemical composition, weight, and geometric shape of the coil. It is important to note that the annealing process is experimental in nature, and the results are obtained through laboratory analyses conducted in the production facility. Analogously, the annealing process can be likened to different chefs cooking the same dish, where even with the same equipment and methods, variations in outcomes may occur. However, through empirical studies, it is possible to obtain closely aligned results with the applied methods and present a reliable technological production process.

The production process encompasses several interconnected stages that form a chain of operations. Following multiple passes on the cold rolling machine, it becomes necessary to trim the edges of the coils. This step is crucial for smoothing and re-deforming coils with cracks on their sides. Moreover, this stage facilitates coil inspection and potential recycling, earning the machine the designation of "recoiler." Depending on demand, the aluminum coils may be opened once or twice during the production process and transported to the recoiler and side cutting area.

The final stage in the process flow encompasses tension leveling, trimming, and washing. In this stage, coils from cold rolling or heat treatment undergo stretching and straightening processes. The sides of the coils are trimmed for the final time according to specific requirements. The surface of the coils is thoroughly washed and dried before being prepared for sale.

Overall, these interconnected stages contribute to the production of high-quality aluminum coils that meet the necessary specifications and are ready for commercial distribution.

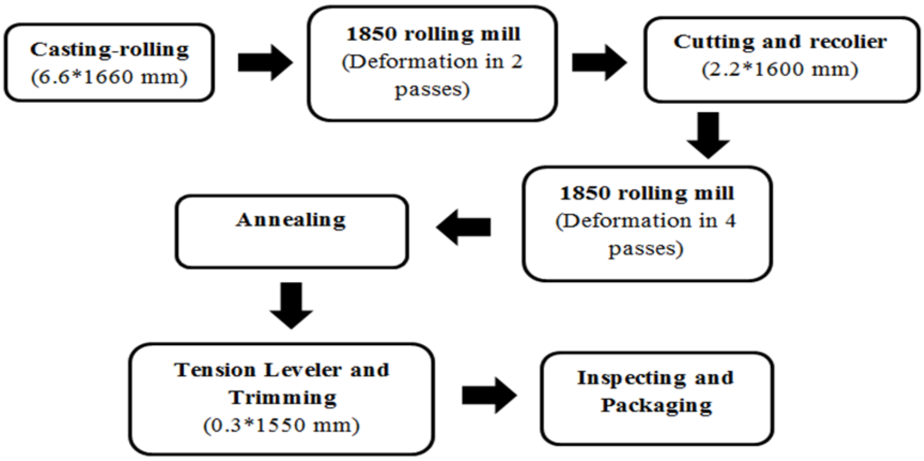

Fig. 2. Production process flow. Authors` finding

The cold rolling process is a vital method used to reduce the thickness of aluminum coils by subjecting them to high pressure and tension between shafts. The multi-stage deformation process involves successive passes to achieve the desired thickness reduction. The extent of deformation is carefully determined based on the chemical and physical characteristics of the rolls involved. The parameters are meticulously analyzed to ensure optimal performance and maintain the desired quality of the rolled aluminum sheets. The primary focus of this process revolves around achieving a deformation rate ranging from 45% to 40%. The cold rolling process thus plays a crucial role in producing aluminum sheets with precise thickness and excellent mechanical properties.

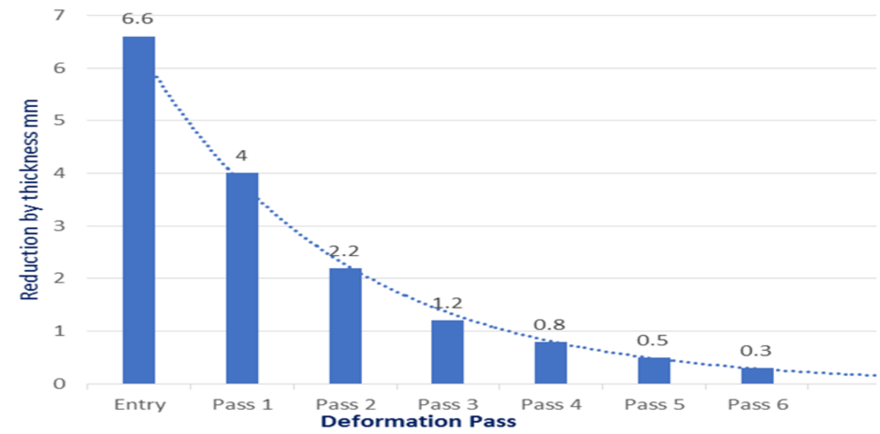

Fig 3. Multiple deformation passes of 1050 alloy aluminum in the cold rolling process
Source: Authors` finding

The total percentage of deformation greatly influences the stiffness of the rolls, necessitating a deliberate softening process to meet specific requirements. In the cold rolling process, this softening is achieved through the annealing stage, wherein the aluminum coils are subjected to controlled heat treatment in specialized ovens. By exposing the coils to high temperatures, the microstructure undergoes recrystallization, leading to improved properties and increased flexibility. The decision on the appropriate temperature in the annealing furnaces is primarily determined through comprehensive experimentation, considering the chemical and physical characteristics of the aluminum coil. This empirical approach ensures that the annealing process effectively aligns with the desired properties and quality standards of the aluminum coils.

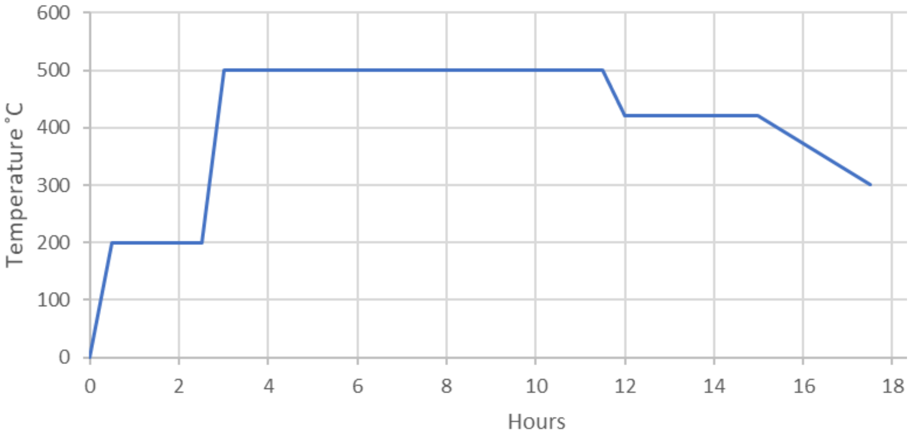

Fig. 4. Annealing process of 1050 H0 aluminum alloy
Source: Authors` finding

Maintaining precise geometric quality that meets the desired specifications is of utmost importance in the cold rolling process, particularly due to the progression towards smaller thickness parameters. The deformation process is meticulously monitored at a micron level, with strict adherence to required standards being a fundamental requirement. With the utilization of contemporary technologies, the production process strives to achieve a deviation rate ranging from -2% to +2%. This narrow range ensures that the final product meets the stringent geometric tolerances and consistently fulfills the demands of the industry.

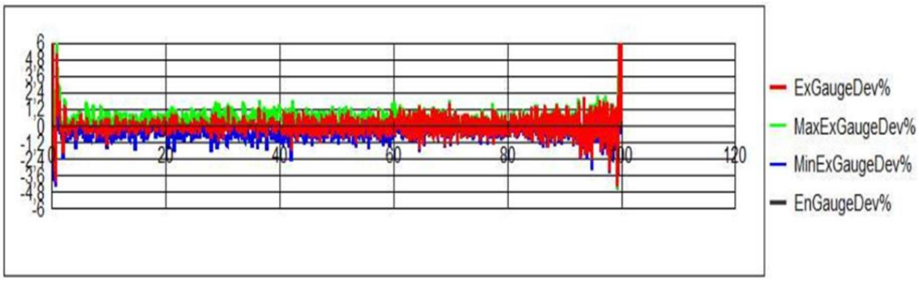

Fig. 5. Deformation pass report
Source: Authors` finding

In the extensive production process chain of aluminum coils, the primary objective is to obtain desirable physical parameters at the final stage. While chemical compositions are key in determining the distinctive properties of each aluminum brand, it is the physical characteristics such as tensile strength, yield strength, and elongation rates that ultimately define the material's performance. These physical parameters serve as crucial indicators for assessing the mechanical behavior and suitability of the aluminum coils for various applications. Therefore, meticulous attention is given to achieving the desired physical properties to ensure the production of high-quality aluminum coils that meet the specific requirements of end-users.

Al	Fe	Si	Mn	Zn	Cu	Mg	V	Ti
99.59%	0.223%	0.128%	0.0026%	0.0064%	0.0019%	0.0006%	0.012%	0.0163%

Tensile Strength Rm MPa		Yield Strength Rp 0.2 MPa		Elongation %	
Request	Factual	Request	Factual	Request	Factual
65-95	84	≥20	42	≥20	28

Fig. 6. Laboratory results of experiment on 10 ton weight 0.3-1500 mm 1050 alloy H0 aluminum coil produced by cold rolling process

Within the aluminum cold rolling production process, a series of meticulous quality control measures are implemented to ensure the production of superior aluminum coils or sheets. These measures include tension leveling, trimming, slitting, cleaning, washing, and packaging. Each step is carefully executed to guarantee dimensional accuracy, preserve surface integrity, achieve optimal cleanliness, and provide adequate protection for the final products. These stringent quality control procedures are essential in meeting the exacting requirements of diverse industries. By adhering to these comprehensive quality control measures, the production process strives to deliver aluminum coils or sheets that consistently meet the highest quality standards, satisfying the demands of customers across various sectors. The cleanliness and smoothness of the roll surface are crucial quality indicators in the aluminum production process. Therefore, maintaining cleanliness, particularly of the machine and shafts, is of utmost importance throughout all stages of production. Regular cleaning of the shafts is essential, and the purity of water and other substances utilized in the process should be regularly assessed through laboratory analysis. By diligently adhering to these practices, the production process ensures that the roll surfaces are free from contaminants, promoting optimal product quality and minimizing the potential for defects.

4. Conclusion

The primary objective of this research was to investigate the physical processing of aluminum coils using cold rolling technology. Additionally, the study aimed to visually demonstrate the influence of chemical composition on the resulting physical characteristics. The research focused specifically on the 1050 alloy, which was selected from a series of aluminum alloys for empirical analysis. It is important to acknowledge that this research represents a foundational step in the exploration of aluminum coil processing. Future studies can build upon these findings by investigating additional alloys, refining processing methods, and exploring other factors that may affect the physical characteristics of aluminum coils.

Through empirical research conducted on an aluminum coil with defined geometric dimensions, various stages of the technological process flow, including deformation, annealing, and deviation indicators, were described. The scientific validity of this work is derived from the direct analysis conducted within the internal laboratory of an industrial enterprise. The empirical data presented in this study can be valuable to both field researchers and manufacturers in the industry.

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