INVESTIGATION OF THE EFFECT OF RECRYSTALLIZATION ON THE MECHANICAL PROPERTIES OF HIGH-NICKEL ALLOY SHEETS DURING ROLLING

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Abstract: The article investigates the effect of the recrystallization phenomenon occurring during the hot rolling of sheet materials made from high-nickel alloys on the mechanical and structural properties of the metal. During the study, the influence of the degree of deformation, rolling temperature, and cooling rate on grain size, strength, and plastic properties was scientifically analyzed. The obtained results are of significant importance for optimizing the sheet rolling technology of high-nickel alloys.

Keywords: high-nickel alloy, sheet rolling, recrystallization, grain structure, mechanical properties, deformation.

Introduction: High-nickel alloys (Ni ≥ 30-60%) are distinguished by their heat resistance, high strength at elevated temperatures, and corrosion resistance. These properties ensure their wide application in high-demand industries such as power engineering, aviation, space technology, and the chemical industry. At the same time, the technological processing of high-nickel alloys is a complex process, since significant changes occur in the microstructure of the metal during hot forming processes such as sheet rolling.

During the hot rolling process, the metal undergoes plastic deformation, which leads to the elongation of the initial grains and an increase in dislocation density. When the temperature and degree of deformation reach a certain critical value, the recrystallization process begins. During this process, old dislocations are eliminated and a new, fine-grained and uniform structure that is energetically stable is formed. As a result, the mechanical properties of the metal, particularly strength, elongation, and impact toughness, are improved.

Therefore, studying the mechanisms of recrystallization during the hot rolling of high-nickel alloys is scientifically and practically important. These studies are essential for optimizing metallurgical process parameters, ensuring stable product quality, and producing sheet rolled products with high performance properties. By properly controlling the recrystallization process, it is possible to reduce internal stresses in the metal, control grain size, and maximize strength properties.

Research Methodology: Sheet blanks made from an industrial high-nickel alloy containing 40-55% Ni were selected as the research object. Rolling experiments were carried out under laboratory conditions using a two-high hot rolling mill.

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Main technological parameters:

Rolling temperature: 950-1150 °C;

Total deformation degree: 20-60%;

Rolling speed: 0.6-1.2 m/s.

Structural analysis was carried out using metallographic methods. Grain sizes were determined using an optical microscope and evaluated according to the ASTM E112 standard. Mechanical properties were determined through tensile testing (σ0.2, σu, δ).

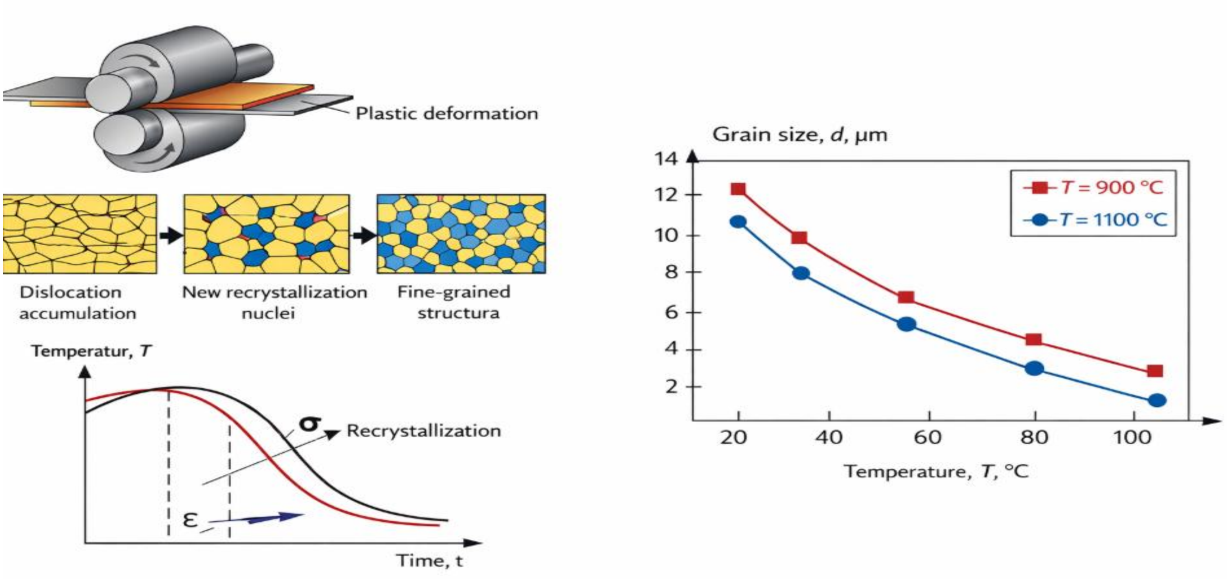

Figure 1. Recrystallization during sheet rolling of high-nickel alloys and changes in grain size.

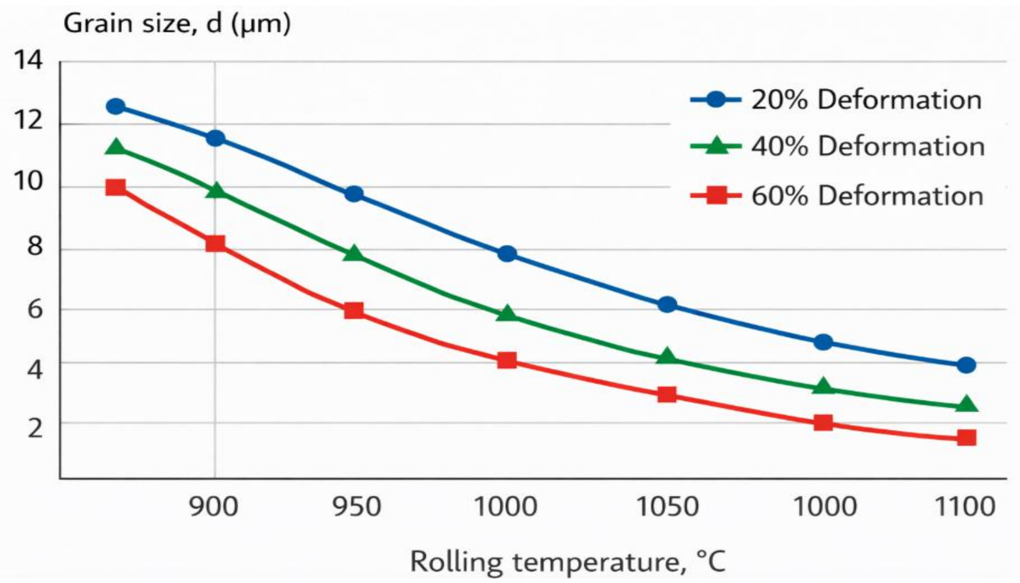

Figure 2. Change in grain size as a function of rolling temperature and total deformation (recrystallization intensity in the 900-1100 °C range).

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Recrystallization Mechanisms and Their Effect on Metal Properties: During the hot rolling process, the recrystallization phenomenon in high-nickel alloys occurs through two primary mechanisms: nucleation and grain growth. As a result of the initial plastic deformation, the dislocation density in the metal increases significantly, leading to the formation of energetically unstable regions. With the onset of recrystallization, new, stress-free, and energetically stable grains form in these regions. Consequently, the metal's ductility improves, internal stresses decrease, and resistance to deformation is enhanced.

The grain size and distribution directly affect the mechanical properties of the metal:

Yield Strength ($\sigma_{0.2}$) - This parameter mainly depends on dislocation density. During recrystallization, the formation of new grains reduces dislocation density, causing the yield strength to decrease by 10-15%.

Elongation (δ) - The formation of new grains and the reduction of internal stresses increase the metal's elongation by 18-25%. This significantly enhances the metal's ductility and impact resistance. Hardness (HRC) - Hardness is directly related to temperature and the degree of deformation. Finer and more uniform grains increase hardness, as the metal becomes more resistant to deformation. However, during secondary recrystallization, grain growth leads to a decrease in hardness and a reduction in the metal's mechanical properties.

At the same time, scientifically controlled recrystallization ensures the preservation of optimal microstructure, reduces internal stresses, and stabilizes the mechanical properties of rolled products. A deep understanding of these mechanisms enables the effective processing of high-nickel alloys under industrial conditions and facilitates the production of high-quality sheet products.

Research Results: Experimental studies have shown that during the hot rolling of high-nickel alloys, temperature and the degree of deformation directly affect the effective onset of recrystallization. Specifically, in the temperature range of 900-1000 °C and when the deformation exceeds 30%, partial recrystallization of the metal is observed. At this stage, the initial grains are partially fragmented, dislocation density decreases, but the structure does not become fully uniform or finely grained.

When the temperature is increased to 1100-1150 °C, complete recrystallization occurs. In this process, the initially deformed grains are entirely replaced by new, fine, and energetically stable grains. Grain size decreases by 2-3 times, significantly improving the metal's microstructure.

The recrystallization process affects the mechanical properties of the metal as follows:

Yield Strength ($\sigma_{0.2}$) decreases by approximately 10-15%, as the internal dislocation density is reduced and the metal becomes more ductile.

Elongation (δ) increases by 18-25%, indicating a significant improvement in the metal's ability to undergo plastic deformation.

Structural Uniformity is considerably enhanced, meaning that grains in the metal's microstructure become more uniform and finer, ensuring stable mechanical properties.

At the same time, uncontrolled recrystallization or processing at excessively high temperatures can lead to secondary recrystallization, resulting in grain growth and a reduction in strength properties. Therefore, it is essential to scientifically determine and strictly control temperature and deformation parameters during the sheet rolling of high-nickel alloys.

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Table 1. Changes in grain size and mechanical properties depending on rolling temperature.

"Rolling Temperature, °C"	"Average Grain Size, d (μm)"	"Yield Strength, $\sigma_{0.2}$ (MPa)"	"Ultimate Tensile Strength, σ_b (MPa)"	"Elongation, δ (%)"	"Hardness, HRC"
900	11,5	420	680	18	235
950	9,2	400	660	20	225
1000	7,0	375	630	23	210
1050	5,1	350	600	26	195
1100	3,2	325	570	29	180

"Table 2. Effect of temperature and deformation degree on mechanical properties during recrystallization."

"Rolling Temperature, °C"	"Deformation, %"	"Average Grain Size, d (μm)"	$\sigma_{0,2}$ (MPa)	σb (MPa)	δ (%)	HRC
950	30	9,2	400	660	20	225
1000	40	7,0	375	630	23	210
1050	50	5,1	350	600	26	195
1100	50	3,2	325	570	29	180

Discussion: The obtained experimental results indicate that the recrystallization process in high-nickel alloys is explained by the redistribution of dislocations and the formation of new, energetically stable grains. Internal stresses and microscopic defects generated under deformation increase the number of dislocations in the metal structure. The recrystallization process eliminates these dislocations, forming fine and uniform crystalline structures. As a result, the metal's ductility increases, internal stresses decrease, and resistance to deformation improves. Experiments show that optimal selection of temperature and deformation degree (temperature 1050-1150 °C, deformation 40-50%) allows for the effective initiation and completion of recrystallization. Under these conditions, the resulting structure is uniform and finely grained, maximizing the improvement of the metal's mechanical properties.

However, at excessively high temperatures, secondary recrystallization occurs. In this process, grains grow and merge, leading to a loss of fine-grained structure. Consequently, the metal's strength properties decrease, elongation reduces, and the risk of microcrack formation on the surface increases. Therefore, strict control of the recrystallization stage is required in sheet rolling of high-nickel alloys. This ensures the preservation of an optimal microstructure, reduction of internal stresses, and stable quality of the rolled products.

The results also provide a basis for optimizing the industrial sheet rolling process of high-nickel alloys and for scientifically determining production parameters. This is crucial for producing high-performance structural materials, particularly in the aerospace, energy, and chemical industries.

Conclusion: The research results indicate that the recrystallization process in sheet products made from high-nickel alloys significantly improves both the structural and mechanical properties of the metal. Recrystallization eliminates the initially deformed and heterogeneous structures, forming fine-grained and uniform crystalline structures. This, in turn, enhances the alloy's strength, elongation, impact resistance, and elastic properties.

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Experimental studies show that the optimal temperature range for rolling high-nickel alloys is 1050-1150 °C. At this temperature, applying deformation of approximately 40-50% allows the recrystallization process to start and complete effectively. As a result, the grains formed are small and uniform, ensuring stable and high mechanical properties of the metal.

Furthermore, recrystallization reduces internal stresses, eliminates microscopic defects, and improves the surface smoothness of the rolled product. This ensures long-term durability and reliability when high-nickel alloys are used as sheet products under industrial conditions.

The scientific findings can be applied to optimize the sheet rolling technology of high-nickel alloys and to improve the rolling process. Controlling metallurgical process parameters allows the production of high-quality products with uniform properties. These results are also of practical importance in manufacturing high-performance structural materials and components for the aerospace and energy industries.

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