

The Study on the Microstructure and Mechanical Properties of the Nodular Indefinite Chilled Iron Containing Ni

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Ni 함유 NICI(Nodular Indefinite Chilled Iron)의 미세조직과 기계적성질에 관한 연구

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Abstract

The effects of adding Ni on microstructure and mechanical properties of Nodular Indefinite Chilled Iron (NICI) were studied. Thermal fatigue, hardness, tensile properties, wear resistance, are very important factors for NICI used for hot working roll and wire rod mill. The results show that addition 4% nickel has changed pearlite to bainite. Bainite matrix is superior to pearlite matrix on wear resistance, hardness and strength and will increase performance lifetime of NICI conventional roll material. Based in the bainitic microstructure, hardness and tensile property increase up to 48 HRC and 72 kg/mm², respectively.

초 록 : NICI재의 미세조직 및 기계적 성질에 미치는 Ni 첨가원소의 영향을 연구하였다. 선재공장의 열간압연롤재로서의 NICI재는 내열 피로크랙성, 경도값, 인장성질, 내마모성이 매우 중요하다. 주방상태에서 4% Ni 첨가로 주요 기지상인 퍼얼라이트상이 베이나이트상으로 변화되었다. 베이나이트상을 주요 기지상으로 가지는 4% Ni 첨가 NICI재는 퍼얼라이트상을 주요 기지상으로 가지는 통상의 NICI재에 비해서 경도값(HRC 48) 및 인장강도값(72 kg/mm²)이 우수하였으며, 이는 선재압연롤 재료로서 우수한 성능을 발휘할 수 있을 것으로 예측된다.

Key words : NICI, Nickel content, Bainite structure, Hardness, Tensile strength, Roll material.

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1. Introduction

Roll materials are expected to have extended implementation lifetime due to minimize the production cost, increase level of productivity and maintain the quality of products. During the service, working rolls are exposed to the thermal fatigue, mechanical fatigue, wear and impact therefore, good thermal, mechanical, and tribological properties are required.[1] Commonly, nodular indefinite chilled iron (NICI) is used for conventional rolls and produced through metal mould casting. Despite of that, properties of conventional roll's and its performance are still far from expectation. This was proven with the presence of crack located on the surface and side part of rolls as shown in Fig. 1. Moreover, the diameter of roll has changed because of the wear process occurred on the roll's surface. The constituents of conventional roll materials are pearlite, together with graphite and

cementite The mechanical properties of pearlite phase especially hardness strength and toughness are relatively lower compare to bainite phase. Since bainite has extraordinary properties compare to pearlite phase, so it is essential to establish bainite structure in Indefinite Nodular Casting Iron for roll materials. The research is conducted to improve the mechanical properties of NICI by using Ni as major alloying elements replace pearlite into bainite matrix.

2. Experimental Procedures

The surface and phase structure of conventional roll were analyzed using microscopic analyzer image system and Scanning Electron Microscope (SEM). Chemical compositions of experimental alloys are given in Table 1. Specimens were produced using metal mould casting with 400 kg of total weight. The modification of Ni content has been done to

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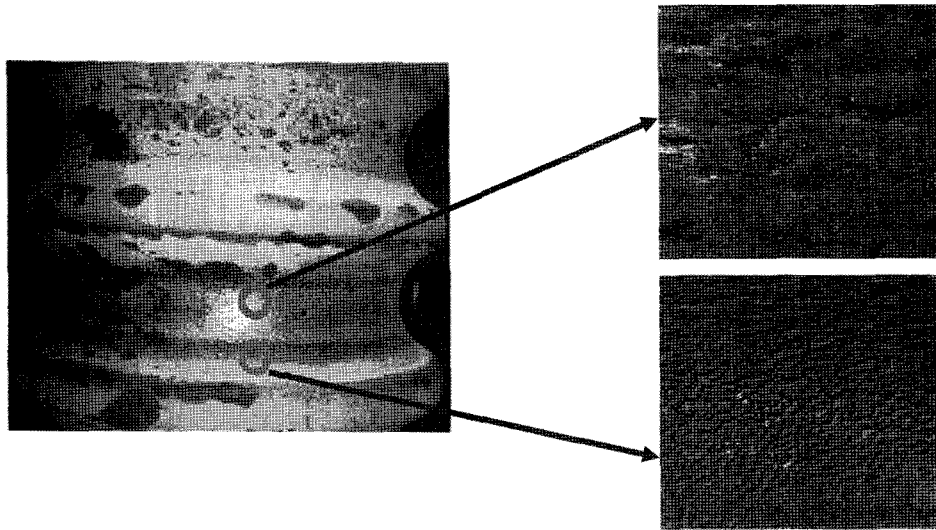


Fig. 1. Crack Indications at the center and side part of conventional roll surface.

Table 1. Chemical Composition of conventional roll and new development roll material

	C	Si	Mn	Mo	Cr	Mg	Ni	Fe
Conventional roll	~3.2	~1.8	~0.45	~0.5	~0.6	~0.06	~2.00	Bal.
Specimen 1	3.21	2.00	0.21	0.21	0.49	0.05	4.05	Bal.

promote bainite rather than pearlite structure in the matrix. After the control cooling process was completed, then the samples were heat treated in a furnace for stress relieving process at various temperature (400, 500 and 600°C) for 16 hr. to minimize residual stress and increase the strength. Metallography specimens were prepared by grinding the specimen with silicon carbide up to a grit size of 1200 and were then etched by 2% natal. Scanning Electron Microscopy analysis were performed under Hitachi S-4200 with 20 KV of voltage.

3. Research Result

3.1 SEM image analysis

Fig. 2(a) and (b) show Scanning Electron Microscopy of conventional roll and specimen 1, respectively. It is clearly

observed that, the constituents of conventional rolls are pearlite (40-70%), graphite (2-4%) and carbide (15-25%), while specimen 1 consist of bainite, graphite and cementite. There is no significant difference between the shape of graphite and cementite phase both in conventional roll and specimen 1, but the volume fraction of cementite in conventional roll is higher than specimen 1. The cementite phase has a big contribution to the hardness properties that can increase wear resistance for roll materials. Despite of that, a higher content of cementite is also responsible for crack formation on the roll surface because it is highly brittle.

The only significant difference is the matrix structure where conventional roll is dominated by pearlite while bainite is major phase in specimen 1. This bainite matrix are believed then can increase mechanical properties particularly hardness

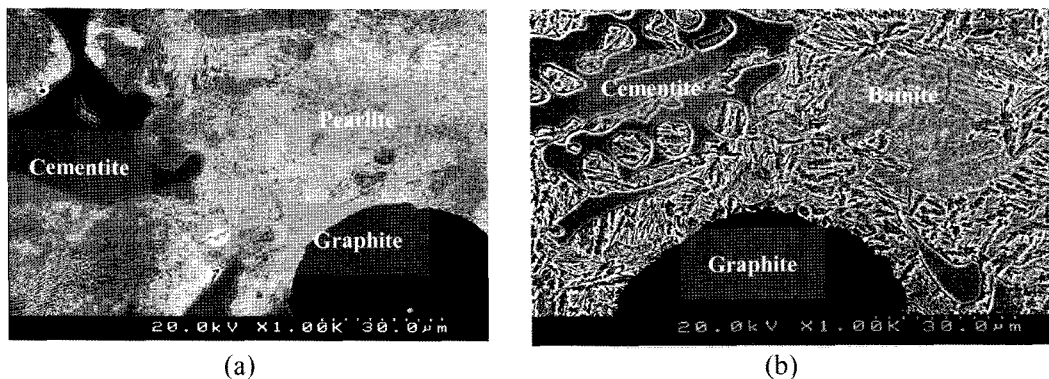


Fig. 2. SEM analysis result showing difference between constituents of (a) Conventional scrap roll, (b) Specimen 1.

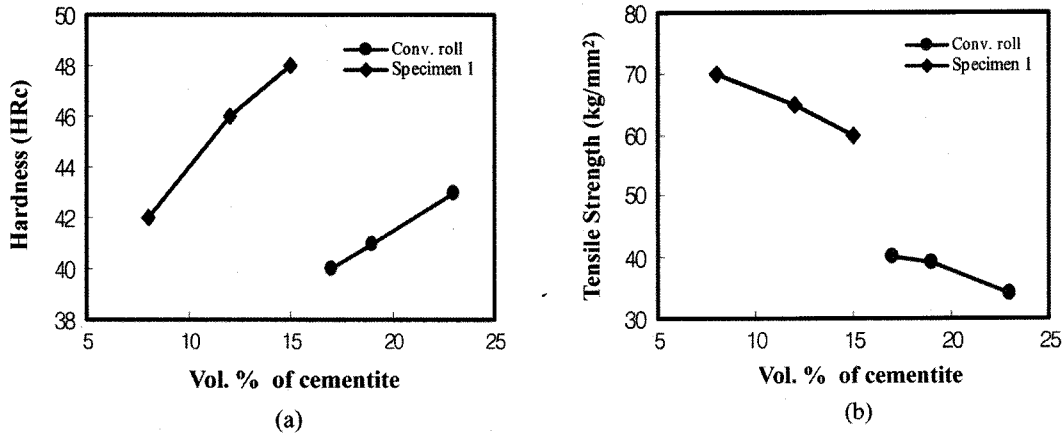


Fig. 3. (a) As cast Tensile properties, (b) As cast Hardness properties, of conventional roll and specimen 1.

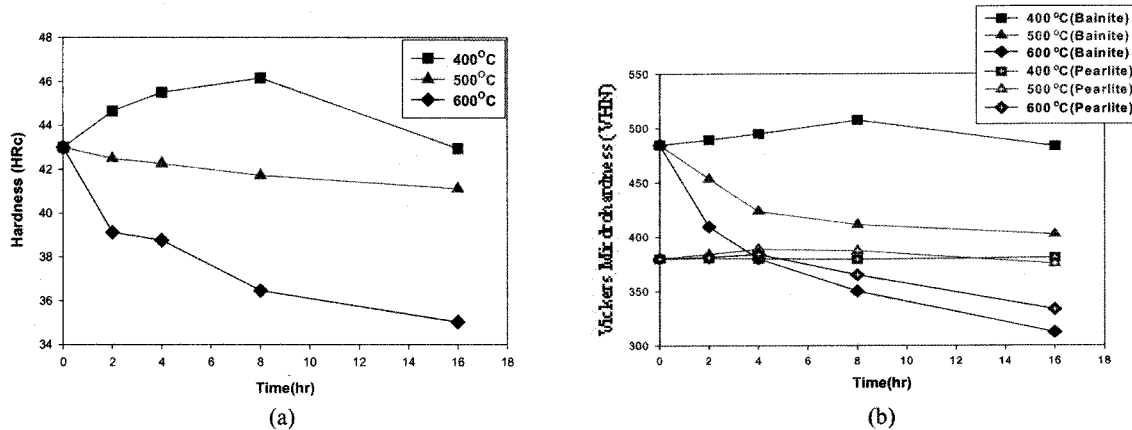


Fig. 4. (a) Rockwell hardness (C scale) of specimen 1 after 16 hr stress relief process, (b) Hardness of matrix pearlite and bainite after 16 hr stress relief process

and tensile strength. The optimum mechanical properties can be achieved when the microstructure consists of retain-carbon enriched stable austenite, together with the bainite as the matrix [2]. Nickel, as one of austenite stabilizer element, [3] could promote bainite structure in the matrix replacing pearlite in the conventional roll. This due to the interaction between some of Ni atoms and moving interface of austenite during transformation will introduce a possible solute drag effect. [4] This effect will increase tendency of bainite transformation rather than pearlite and finally, austenite transforms into bainite. Since the alloy did not contain a proper amount of Si to retard carbide precipitaton, then cementite still can be found in the microstructure.

3.2 As Cast Hardness and Tensile Strength Properties

Fig. 3 show the hardness and tensile strength properties of as cast products. The hardness number of material will increase linearly with accession volume percent of cementite in the structure. Despite of that, as cast hardness properties of specimen 1 is higher than conventional roll material (50 HRC

at 15% volume percent of cementite) even tough the volume percent of cementite is lower than conventional roll.

Bainite matrix is superior in hardness compare to pearlite because bainite phase occurs in separable stages, first is the growth of ferrite and followed by precipitation of carbides. The ferrite of bainite may be in the form of laths or plates containing a dislocation of structure, and interaction of the dislocation will result extraordinary hardness properties.[5] Meanwhile growths of pearlite occurs at a common transformation front with the austenite. The growth of ferrite and cementite in the pearlite phases is coupled and their compositions are complementary since the carbon which cannot be accommodated by the ferrite is incorporated with cementite.[6] Contrary to hardness properties, increasing volume percent of cementite will deteriorate tensile properties of materials. Tensile strength of specimen 1 is extremely higher than conventional roll (70 kg/mm² at 8% volume percent of cementite). This is mainly caused by the existence of bainite phase and low volume percentage of cementite in the specimen 1. From the point view of dislocation density, the bainite

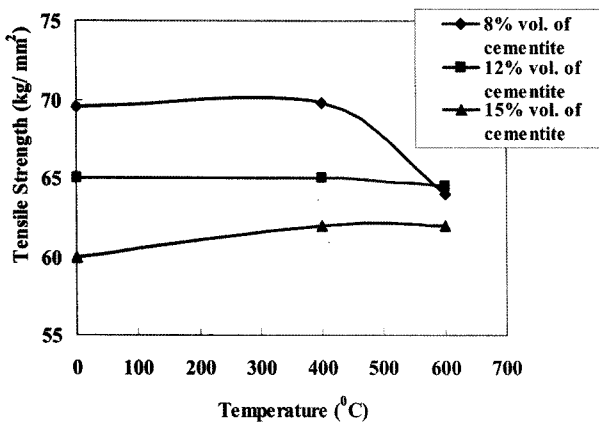


Fig. 5. Tensile Strength properties of specimen 1 at different temperature after 10 hr stress relief process

microstructure contains more dislocations than pearlite, so when external load is applied, it will cause dislocation interaction and result higher tensile strength. Cementite is a hard and brittle phase so it retrieves high tensile strength of materials, it is important to minimize the volume fraction of cementite phase in the structure.

3.3 Hardness and Tensile Strength Properties after Stress Relieved Process

It is already known that casting process produce residual stress and might be decrease the overall performance of the materials. The residual stresses can be reduced or even eliminated by subcritical heat treatments, called stress relieving. The process of heating to and cooling from the stress-relieve temperature must be done slowly in order to avoid introducing new thermal stresses and possible cracking during the stress-relief treatment itself. The result of hardness after stress relieve is shown in Fig. 4.

Based on Fig. 4(a), the hardness of specimen 1 increases to the maximum number (46 HRC), during the stress relieved at 400°C. The substantial explanation of this relies on bainite microstructure existed in the matrix of specimen (Fig 4(b)). During stress relieved process of bainite structure, some martensite phase are formed coexist with very fine carbide precipitation which are responsible for increasing hardness properties. Contrary to bainite, the hardness of pearlite phase relatively constant because pearlite phase is stable, thus there is no fine carbide precipitation and formation of martensite phase throughout the stress relieved process using 400°C of temperature.

The other fact obtained from Fig. 4(a) is that the hardness number of specimen 1 is decreasing until 36 HRC at 600°C and 16 hr of temperature and time process respectively. This is occurred because by using high temperature in the heat treatment process, particularly stress-relieving, the grain tend

to growth and become coarse, thus deteriorate the hardness property. Based on the linearly correlation between the grain size, energy activation, time and temperature,[7] it is notified that the increasing time and temperature of stress relieve process enlarged the grain size.

It is clearly seen form Fig. 5 that the tensile properties of specimen 1 are increasing relatively as the temperature raises. After 400°C of temperature, the tensile strength of 8% volume of cementite unexpectedly decreased to 64 kg/mm², indicating that the optimum temperature of stress relieving is 400°C.

4. Conclusion

Adding of Ni content in the NICI as roll material will change pearlite and promote bainite structure in the matrix but do not prevent cementite precipitation during bainite transformation, therefore cementite still can be observed in the final microstructure of specimen 1. The existence of bainite phase in the matrix and less percentage volume of cementite has increased tensile strength and hardness properties of specimen 1 (70 kg/mm² and 50 HRC for tensile strength and hardness, respectively). During the stress relieved process of bainite structure, some martensite phase are formed coexist with very fine carbide precipitation which are responsible for increasing hardness properties. The tensile properties are relatively increased with rising stress relieved temperature, maximum tensile strength was 72 kg/mm² at 8% volume of cementite, and achieved using 400°C of temperature. Bainite matrix structure is superior to pearlite structure in hardness and tensile strength so it will improve overall performance of roll materials.

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