Most urban people must have known the painstaking struggle of daily commuting traffic. In Jakarta, the traffic is so severe that we spend 5 hours travel on a route which supposedly only took 1 hour. So, in 2017, Indonesian Government proposed to build an elevated toll road from Jakarta-Cikampek as a solution for this condition. In other countries, infrastructure of the elevated toll road was built from concrete and steel. But Indonesia is mostly using concrete to make the structure due to abundant supply of limestone, which is raw material to make concrete.

In comparison of concrete and steel, steel is lighter, has higher strength which can accommodate longer distance in between pier, which can reduce the cost and time of construction. Considering these advantages of steel for bridge construction, our government decided to use steel for the elevated toll road in Jakarta-Cikampek Project II which would be the first case in our country. This project needs high strength steel with minimum 570 MPa of TS. Usually, accelerated cooling and heat treatment facilities are required to produce high strength steel like JS-SM570TMC.

Albeit lacking in those facilities, PT. Krakatau POSCO opted to optimize the existing facilities in order to conquer the challenge of this Jakarta-Cikampek’s 38KM Elevated Toll Road. PT. Krakatau POSCO produced the material with ultra-high temperature reheating instead of the water cooling condition, and make adjustment on rolling parameter and chemical composition to achieve the targeted properties. Up until now, the supply for this project is still on going.

**Keywords**: elevated toll road, optimize existing facilities, JS-SM570TMC

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1. Introduction

Thermo Mechanical Control Process (TMCP) is a microstructural process control technique through combining controlled rolling and cooling. According to the definition by IACS (Fig.1), TMCP were divided to two techniques, TMR (Thermo-Mechanical Rolling) and TMR with accelerated cooling process [1]. In this paper the authors will be concentrating to TMR process without accelerated cooling facilities.

Fig. 1 TMCP by IACS

With the limited facilities, PT. Krakatau POSCO (PT.KP) can achieve the producing of TMR material, in order to answer the market demand for the 60kg material grade such as JS-SM570TMC, EN-S460M, and API X65M. PT.KP is using TMR process as a substitution of heat treatments facilities which require additional material handling and rolling facilities.

TMR process has several advantages that can help overcome the addition of major alloying elements, conventional heat treatment and the limitation of accelerated cooling facilities of the mill. TMR can improve both strength and toughness at the same time through grain refinement strengthening mechanism [2]. TMR can also reduce the alloying addition, and thus realizes other advantages such as improved weldability [3]. At the same C_eq (carbon equivalent) level, the strength of TMR steels is higher than those of conventional steels; Fig. 2 shows the relationship between tensile strength and C_eq value. And Fig. 3 shows the relationship between grain size and toughness, the decrease of grain size will improve the toughness. The strength of TMCP steels is higher than normalized steel with the same or lower chemical composition. As TMR steel affords good strength, toughness and weldability, they are highly valued in industries such as shipbuilding, offshore structures, pipeline and building construction [1].
The rolling control starts from the reheating furnace of the slabs itself which the temperature can be reached over than 1180 °C. In the rolling stage, deformation in the non-recrystallization region of austenite may be carried up to 80% of reduction ratio in thickness to obtain the desired grain refinement [5]. The TMR concept is to achieve high strength and high toughness through the transformation of austenite to fine and uniform ferrite microstructure by the deformation of austenite in the non-recrystallization region with carried out the intermediate (D) and final rolling temperature (E), shown in Fig. 4 [5].

Plastic deformation at the lower temperature will promote fine grain size and retards the precipitation. To obtain the optimum ferrite refinement, it is necessary to maximize the area of austenite grain boundary. The austenite grain boundary is the site of the nucleation of ferrite phase. In the nutshell, fine grained austenite generates fine grained ferrite [2].

In order to achieve the fine grained it is necessary to add some micro alloyed such as Nb, V, and Ti as a grain refiner element. In this case JS-SM570TMC grade was using the small
addition of micro alloy, Nb and Ti. Especially for Nb element, Nb provides the significant strengthening in rolled steel through the presence of NbCN (Niobiumcarbonitride) and NbC (Niobiumcarbide) carbide. The advantage of Nb starts from reheating the slabs. The carbide will be precipitated and retarding the growth of deformation and recrystallization of austenite grains. These precipitates maintained a fine grain austenite before rolling process.

Higher heating temperature will dissolve all Nb carbonitrides in order to optimizing of precipitation forming [6]. These fine austenite grain will transform to fine grained ferrite when the rolling process. The precipitates strongly retard the recovery and recrystallization of austenite during the hot deformation [6]. Retarded austenite recrystallization produces the formation of fine pancake austenitic grain structure at the end of hot deformation process. This structure will leads into the finer ferrite grain size

In general, thermo mechanical control process is highly dependent on the rolling parameters (reheating temperature, reduction load, reduction ratio, deforming temperatures, oscillation, pass number, finish rolling temperature) and chemical composition arrangement. The purpose of thermo mechanical rolling is to obtain the high mechanical properties by controlling the final microstructure. This paper will focus on the mechanical result and microstructure of JIS G 3106, JS-SM570TMC grade 20~22 mm thick.

2. Materials and Method

The slab is produced in PT. Krakatau POSCO. The steel plate grade is JS-SM570TMC (from JIS G 3106:2015). The steel slab is produced from PT.KP blast furnace, followed by desulphurization in Kanvara Reactor, blowing by oxygen to refining
the molten iron in Converter and secondary refining process through the Ruhrstahl Heraeus (RH) for several minutes to make sure the steel was clean from impurities. The molten steel was poured from the mold to the Continuous Casting to produce the slabs and hot rolled into the plate without accelerated cooling facilities in plate mill facility.

There are three rolling schedule, 20mm, 21mm, and 22mm with the same heat number. The slab dimension is (230 x 2300 x 3880mm) which reheated 4 hours with the temperature over than 1180°C in the reheating furnace. The hot slab is extracted and rolled with 4-High Reversing Mill Machine with maximum 9000 Ton force; rolling schedule can be seen on the Fig. 6.

![Fig. 6 TMCP Rolling Schematic](image)

The first schedule: After the slab is extracted (A – B), it is rolled until the C and oscillated until D region with more short time to entering the non-recrystallization zone and then rolled again (D – E) until reaching the desired 20mm thickness with the increasing finish rolling temperature (Ar3 zone). The second schedule: The slab is deforming until the C section and the oscillated (C – D) until non-recrystallization zone in intermediate time, then the slab is rolled until desired 21mm thickness (D – E) with the lowering finish rolling temperature. The third schedule: It is rolled until the C section and the oscillated until D region with the longer oscillation time. After then the slab is rolled until desired 22mm thickness (D – E) with the intermediate finish rolling temperature.

After the rolling process is finish, the mechanical testing is conducted. The test were used in this study are tensile test, impact test and ferrite grain size measurement test. The testing is following the standard based on JIS G 3106 : 2015 “Rolled steels for welded structure” [7], JIS Z 2241 : 2011 “Metallic materials – Tensile Testing – Method of test at room temperature” [8], JIS Z 2242 : 2005 “Method for Charpy pendulum impact test of
metallic materials” [9]. Tensile test specimen is using the No. 4 test piece (round tensile test specimen) according to JIS Z 2241 and for the impact test, this study using standard Charpy V-notch test piece which according to JIS Z2242 and for the grain size measurement based on JIS G 0551:2013 “Micrographic determination of the apparent grain size” using the three circle intercept method [10].

Tensile test specimen is taken transverse to the rolling direction and tested using ZWICK ROELL machine test, charpy impact test is taken parallel to the rolling direction and tested on -23°C with the minimum average of value is 48 J using TINIUS OLSEN testing machine, and ferrite grain size measurement test is taken from ½ surface with the magnification 500X using Leica image analyzer after etched using 3% nital to measure the grain size.

3. Result and Discussion

The mechanical testing result can be seen in the table 1. All the mechanical result is surpassing minimum requirement that stated in JIS G 3106, see the table 2. The result shows that the thermo mechanical control process without the accelerated cooling can achieve the high mechanical properties. The yield strength can achieve 510~550 MPa, the tensile strength can achieve 604~640 MPa and the toughness in -23°C can achieve 199~233 J. The mechanical properties are very dependent on their microstructures. Fine ferrite grain size is strongly influenced by the rolling method. The study using three circles intercept method to measure ferrite grain size, then the sampling is taken on the center of the plate or ½ thick. See the Fig. 7 for the ferrite grain size result. It is observed that the thickness 21 mm has a finest grain size than the other two, with scale 12.04. The
finer grain size is counted by grain size number. Thickness 21 mm (specimen 2) has the lower finish rolling temperature, lowering rolling temperature will finer the grain size.

![Fig. 7 Grain Size Result](image)

The purpose of controlling the high reheating furnace temperature is to dissolve completely the Niobium element which has a role to produce the Nb precipitate. Then adjusting the rolling parameter, proper chemical composition (most important parameters to achieve the high strength material if do not have the accelerated cooling facilities). In the recrystallization region, the coarse austenite grain is refined by the presence of Niobium precipitate which retards the grain growth of the austenite grain and followed by the plastic deformation process. The oscillation is important to waiting the decreasing of temperature in order to entering the non-recrystallization phase which followed by the reduction until the above the Ar3 temperature, where the austenite grain size is already fine and in pancake forms. After the rolling is finished above the Ar3, during the cooling, the ferrite will nucleate on the deformation band as well as fine austenite grain boundary, which will give the finer ferrite grain. The illustration can be seen on the Fig. 8.

![Fig. 8 Grain Boundary Transformation on TMCP Steel](image)
4. Summary and References

Summary

(1) The mechanical results show the good strength, 510~550 MPa on yield strength, 600~640 MPa of tensile test, 32~38% of elongation and toughness 200~230 J, even the toughness is tested on the -23 °C.

(2) The hot rolling with controlling the reheating temperature, rolling on the recrystallization and non-recrystallization region, control the finish rolling temperature, and adjust the proper chemical composition is strongly influenced to achieve the high mechanical properties if do not have accelerated cooling facilities.

(3) Lower rolling (starting to enter α + γ phase) finish temperature can make the grain is finer which make the good strength and toughness.

(4) The presence of the micro alloy element like Nb and Ti is necessary to produce the fine grain through the appearance of precipitate in recrystallization and non-recrystallization zone.

References


[7] JIS G 3106. 2015, Rolled steels for welded structure


[10] JIS G 0551. 2013, Micrographic determination of the apparent grain size