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TECHNOLOGICAL METHODS TO CONTROL THE FINAL PROPERTIES OF THE ROLLED PRODUCT

Rudolf Kawalla, Alexander Nam, Sergey Guk

Institute of Metal Forming,
Technical University Bergakademie Freiberg,
Bernhard-von-Cotta-Str. 4,
Germany, 09596 Freiberg
E-mail: rudolf.kawalla@imf.tu-freiberg.de
alexander.nam@imf.tu-freiberg.de
sergey.guk@imf.tu-freiberg.de

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ABSTRACT

The properties of the hot rolled strip are defined due to chemical composition and process parameters starting with casting, throughout cooling and reheating cycles of continuous casting slab as well as the type of the technological route of hot rolling. The technological conditions comprise a reheating, hot rolling and cooling after hot rolling. The manganese segregation is the one of the properties in terms of microstructure evolution, which impacts negatively on the further processing of hot rolled strip, e.g. in case of pipelines. The influences of chemical compositions on the mechanical properties and on the microstructure evolution will be discussed. Moreover, their effects will be also shown on the examples.

Keywords: C-Mn-segregation, hot rolling,pipeline steel, microstructure, mechanical properties.

INTRODUCTION

Hot deformation is an effective way to influence the final properties of the product. Both physical and mechanical properties can be affected. On the one hand, the source material in conditions of its increased formability can be subjected to high extent of deformation. On the other hand, it is possible to control microstructural changes and related properties through the choice of the heating conditions and time cycles of temperature and deformation degree.

Hot rolling of sheet is one of the metal forming processes, which allows producing up to10 million tons a year of various steel grades per unit. The process also includes strips manufacturing. The possibility of the property controlling of semi-finished products takes place in all stages of the production process starting with heating the strip until cooling it after rolling.

In this article, the effect of carbon and manganese in the context of an emergence of micro and macrosegregation is firstly discussed. Subsequently, the separate aspects of the hot strip production process with regard to their influence on the properties will be shown. The focus thereby is on the processes of heating and cooling immediately before or after deformation. All arguments concern the production of pipe steels, some of which relate to the strips production. Therefore, the current state of pipeline steels development is described. Special attention is paid on the interaction in between production process, microstructure and targeted mechanical properties.

State of development of pipeline steels

Micro-alloyed steels are characterized by a high strength, good toughness and suitable for welding. This combination of properties enables their application in the production of large-diameter pipelines for the gas and oil transport. Moreover, it has essential potential in terms of reduction of wall thickness. These steel sorts are referred to as the pipeline steels [1, 2]. To further requirements can be belonged the resistance against hydrogen-induced cracking (HIC) by application in the acid gas [3, 4], the resistance against stress-induced corrosion (SCC) by underground purposes [5, 7] and high fatigue strength [8, 9]. In terms of strength, the yield strength has been increased in the last 50 years from 65 ksi (450 MPa) to 120 ksi (840 MPa). This is caused due to the modification of material's microstructure, which includes outweighing from the polygonal ferrite up to the fine bainite (intermediate level) (see Fig. 1). The high yield strength of material is one of the main condition for the application in deep water as well as the use in regions where the pressure of transport can be exceed the limit of 170 bar. The multi-phased microstructure (polygonal ferrite, perlite, bainite and martensite) of variety of pipeline steels can be obtained because of suitable combination of a chemical composition, thermo-mechanical treatment (TMT) and accelerated cooling [10]. The typical alloying elements for this purpose are Mn, Nb, V, Ti, Mo, Ni and Cr [4, 5, 11 - 13]. Thus, the interaction of these alloying elements should be taken into account. Lee et al. and Sun et al. showed that the alloyed pipeline steels with Nb and Mo show significantly higher strength-toughness combination in comparison to alloyed pipeline steels with Nb and V [12, 13]. Furthermore, the deformation processes with accelerated cooling contribute to the refinement of microstructure and make suitable formation of strength increasing phases such as the bainite and the martensite and the retained austenite (MRA) [14 - 16].

The kind of resulted microstructure plays a crucial role by setting up of the properties of pipeline steels. However, the current interest is indicated in the formation of acicular bainitic ferrites (AF). It is also argued that the bainitic pipeline steels with pronounced AF+MRA structure evince superior combination of strength and toughness in comparison to the granular bainitic structure with the MRA-fractions. Further, it has been proved, that the formation of the predominant AF+MRA structure requires a thermo-mechanical treatment [12]. There are many investigations, which quantify the different strengthening mechanisms by micro-alloyed bainitic steels taking into account the complexity of microstructure formation. Many researchers have examined both the matrix of acicular structure as well as the inhomogeneity within distribution and the precipitation of carbon and secondary phases [23, 24]. The relation of yield strength and microstructure in terms of total amount of strengthening usually occurs by means of straight-line summation of individual strengthening contributions through the solid solution hardening, grain refinement, precipitation hardening and formation of dislocations [24].

Selection of chemical composition

The chemical composition of meltis selected with purpose to obtain the desired mechanical properties with a high degree of probability. In case of pipeline steels, one of the additional requirement is also corrosion resistance (to hydrosulphuric corrosion). It is primarily associated with purity degree of chemical composition of melting and with forming of micro and macro segregation. While the required purity degree of melting can be adjusted using different types of secondary metallurgical processing. The segregation behavior during crystal-

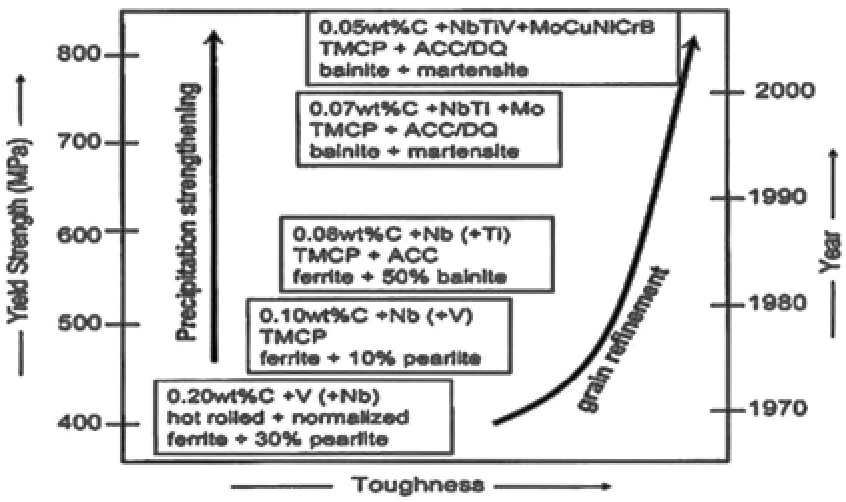

Fig. 1. Development in the field of pipeline steels (TMCP: Thermo-mechanical controlled process, ACC Accelerated cooling, DQ direct quenching) [17].

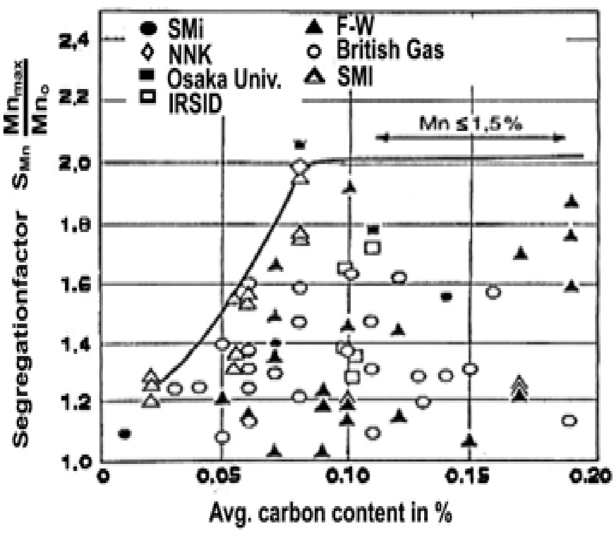

Fig. 2. The effect of carbon content on the behavior of manganese segregation in the central area of the cast slab.

lization depends directly on its chemical composition. Special processing techniques of continuously cast slabs, such as soft reduction, minimize the amount of residual liquid phase between dendrites including in the core of the cast billet, and can thus affect the segregation factor significantly [25]. The studies have allowed revealing the influence of the average carbon content on the amount of a segregationfactor S_{Mn} in the central areas of the continuously cast slab (see Fig. 2).

However, this analysis relates to the manganese content less than 1.5 % and the crystallization conditions of the conventional continuously cast slabs. The importance of central segregation takes place in the context of resistance to hydrosulphuric corrosion, which is indirectly connected with the uneven structure in the core of the strip or strips. A high content of manganese and carbon often causes a change of thermodynamic conditions in the core and the formation of the mixed microstructure with different precipitations promoting the formation of cracks in the process of hydrosulphuric embrittlement. For this reason, in modern pipe steels class> X 80 carbon content is usually regulated in the range below 0.05 % and manganese content is more than 1.5 %.

Production of hot strip and the capabilities to affect its mechanical properties

The scheme in Fig. 3 shows the structure of a semi-continuous hot rolling mill. It consists of a group of heating furnaces, mill stands of preliminary rough and finish rolling, as well as a collecting roller table with appropriate additional devices. For different groups of equipment there are metallurgical processes occurring in the material during its heating, cooling and deformation. They affect the change in the microstructure directly and thus the mechanical properties of the semi-finished product. Their influence must always be considered simultaneously rather than separately.

The technological processes of heating and cooling of the cast slab will be below discussed, which from today's point of view play a special role in energy efficiency, and enable to establish different structural states of semi-finished products.

Heating the cast billet

The heating temperature of continuously cast slabs

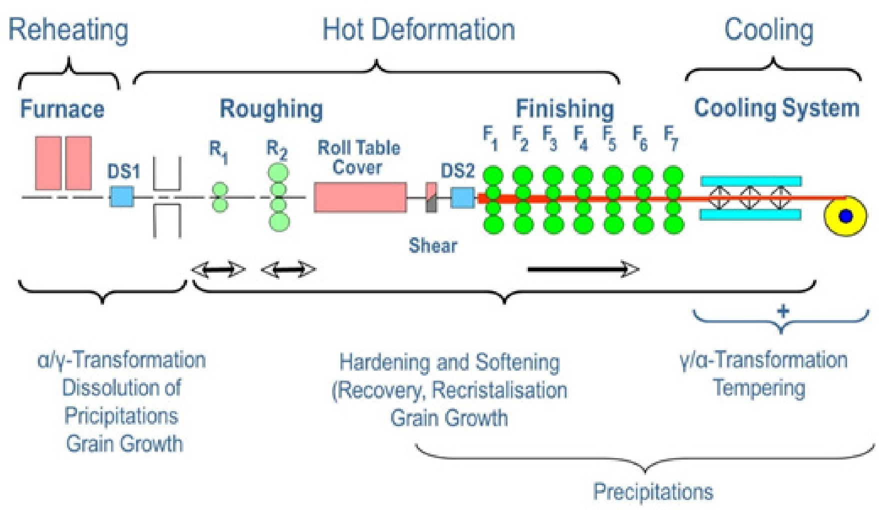

Fig. 3. The structure of semi-continuous hot rolling mill.

in the furnace is selected in terms of achieving desirable temperature at the end of deformation and the formation of a certain phase state of semi-finished before its deformation. This primarily relates to micro-alloyed alloys forming of the carbides and carbonitrides during the slow cooling of continuously cast slabs. The higher heating temperatures are often required for their complete dissolution. It is necessary only from the standpoint of achieving the desired temperature at the end of deformation. The required heating temperature from the viewpoint of dissolving compounds of micro-alloying elements can be calculated using various software packages. Some of them are given in [26, 27]. They take into account the interaction of individual chemical compounds in varying thermodynamic conditions. However, the results of the calculation of most systems are only valid for the conditions of thermodynamic equilibrium. It is usually assumed that they are achieved during the heating process. The current state of development in this area is considered in [28].

The results of solubility of two chemical compounds, which are used for the production of tubal steel grade X80, are shown in Fig. 4. The compositions only differ on the titanium content of 80 ppm, which may be in the form of traces in the original ore, under certain circumstances.

The heating temperature required for dissolution of the vanadium carbonitrides and niobium is about 1150°C. In case of steel with titanium traces (see Fig. 3), the niobium carbonitrides increase their stability and complete dissolution takes place only at a temperature of about 1200°C. Herewith about 95 % of these inclusions are dissolved already at 1170°C. The calculated heating temperature complies with the conditions of equilibrium and does not take into account the heterogeneity of the chemical composition, such as the presence of segrega-

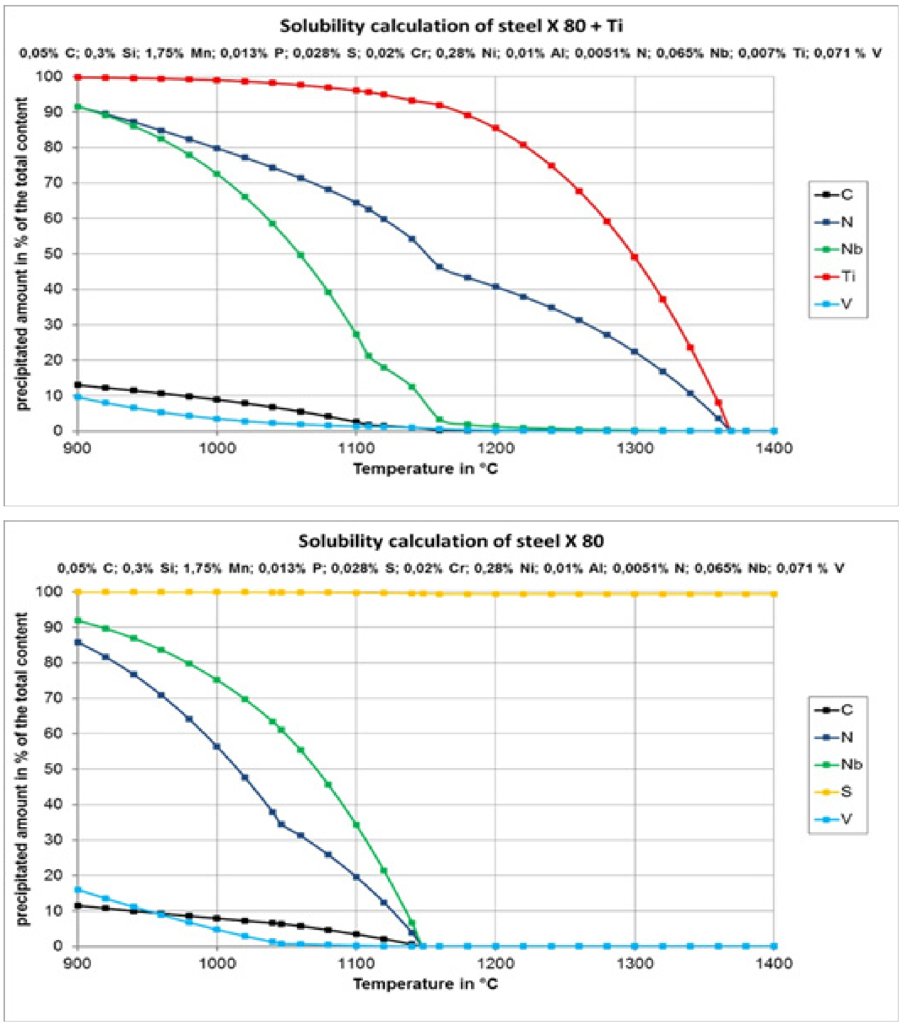

Fig. 4. Results of solubility calculation in steel heating.

tion for example. Therefore, in practice the heating of continuously cast of slabs is carried out up to the temperatures exceeding theoretically calculated for 50°C.

Roll Table and RollCooling

The conditions of strip rolling throughout the mill stands should be selected in order to form after deformation a certain austenitic microstructure, including with the allocated carbonitrides of micro-alloying elements. Regarding austenite grains, it is important that at the end of the deformation they should be practically uniform throughout the material. Mixed and uneven structures contribute to the formation of non-uniformity of the grain after the phase transformation thus reducing the finite viscosity of the semi-finished product.

Cooling at the offtake roll table in combination with the chemical composition of the steel and stability of its austenite has a very high potential of the reliable control of the formation of the structure after the phase transformations and changes in the mechanical properties of material. They can be defined based on thermo-kinetic diagrams of austenite decomposition with the preceding step of deformation. However, the current technical condition of water cooling systems is not particularly suited to implementing complex multistage cooling circuits. The limiting factors here are thickness of the

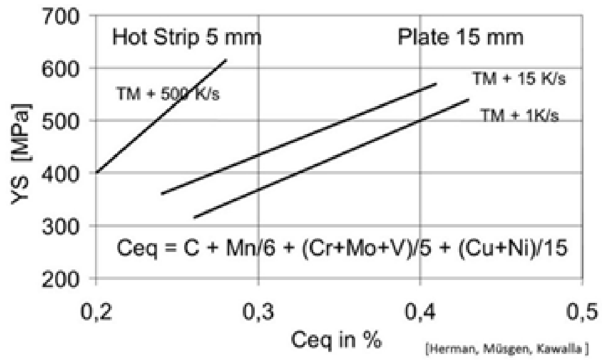

Fig. 5. Relationship between the chemical composition, austenite stability and cooling rate for carbon-manganese steels.

strip, speed of the end of rolling and time. Despite it, some multistage cycles of cooling are being technically implemented now. They can be combined with processes of final cooling of a hot-rolled strip within the roll. Based on these combinations some groups of modern steels are developed [29].

Continuous cooling of the strip leads tothe significant increase of the durability, as shown in Fig. 5 for both strips and hot-rolled strip. This increase depends on the steel chemical composition. In 15 mm, thick strips the hardness of cold-hardened austenite can be increased up to 150 MPa if the cooling rate is about 15°C/s. It is mainly connected with crushing of the ferrite grains. The

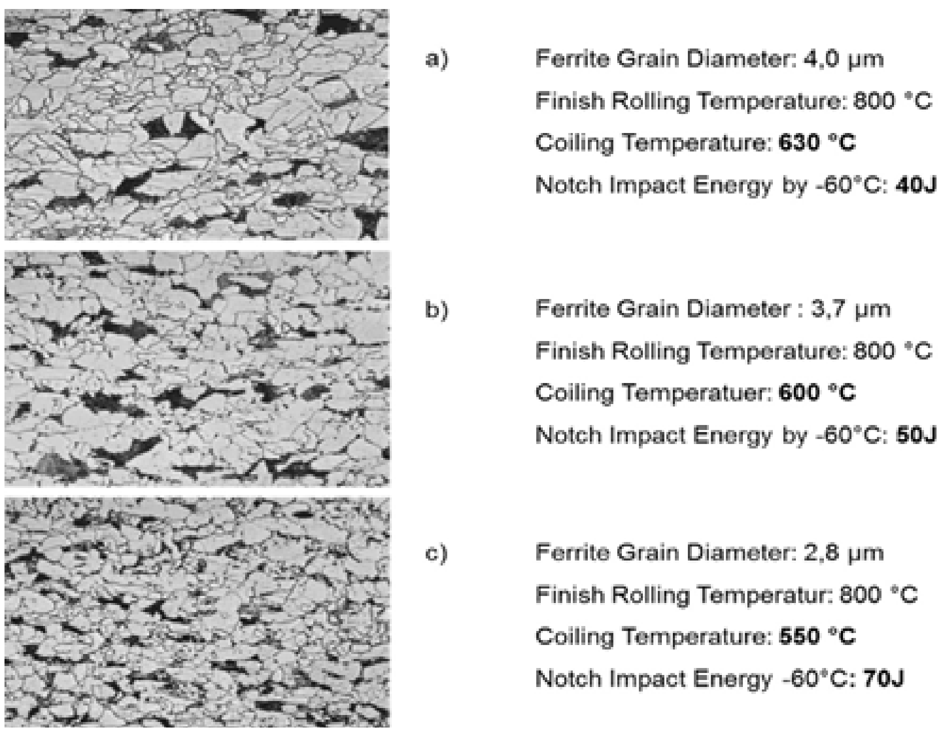

Fig. 6. The effect of coiling temperature on the properties of semi-finished products.

correlation between the chemical composition, austenite stability and cooling speed is described in [30].

Very fast cooling (with a speed about 500°C/s) leads to the bainite transformation and to the increase of the yield strength up to 200 - 250 MPa in the thin hot-rolled strip. However, in case, that the steel has a higher content of the carbon and manganese such fast cooling leads to formation of the brittle martensite. Thus, this type of cooling is suitable either for the multistage quench scheme or only for the low - and ultralow-carbon steel grades (LC-and ULC steel).

The further possibility to influence the properties of the rolled semi-finished product is to select the coiling temperature properly. Its importance in combination with preliminary cooling with the speed of 30°C/s is illustrated in Fig. 6. The lowering of the coiling temperature can significantly increase the impact toughness of the pipe steel 60X as well as thus can also homogenize its microstructure substantially after the phase transformation.

CONCLUSIONS

The deformation conditions have the essential influence on the microstructure evolution and thus on the resulted mechanical properties during the production of flat products. Depending on the kind of rough materials, there are the deformation conditions of hot rolling (i.e. solution state, grain size), the hardening and softening processes, which are accompanied by precipitation processes (i.e. initial state before cooling) and cooling conditions (i.e. phase transformation conditions of non- and low alloyed steels), which influence the static and dynamic properties of rolled products. By setting of the deformation conditions, it should be paid especially attention on the processes of the microstructure evolution and the homogeneity of the microstructure in order to avoid the negative influence on the properties, e.g. on the impact work.

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