JAMME
Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 20
ISSUES 1-2
January-February
2007

Manufacturing of mass-scale products from structural microalloyed steels in integrated production lines

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Received 30.10.2006; accepted in revised form 15.11.2006

Manufacturing and processing

ABSTRACT

Purpose: Technical – economic aspects of the introduction of integrated technological lines for the production of metallurgical products are presented in the work. They have a special importance for microalloyed steels used in different branches of the industry.
Design/methodology/approach: The analysis was carried out on a basis of requirements concerning hot-working of microalloyed steels with high mechanical properties produced by the use of the controlled rolling and thermo-mechanical processing.
Findings: A modification of some well-known integrated lines consisting in the introduction of the cooling machine between roughing and finishing trains, instead of reheating machine gives a possibility to realize a controlled rolling. Moreover, using retention shields makes possible to manufacture the products by the thermo-mechanical processing.
Research limitations/implications: There is a necessity to adjust technological parameters to precise controlling a course of material processes.
Practical implications: Development of demands concerning integrated lines enabling to realize the controlled rolling and thermo-mechanical processing.
Originality/value: Manufacturing mass-scale products from microalloyed steels in integrated energy-saving lines.
Keywords: Technological devices and equipment; Integrated production lines; Structural microalloyed steels; Controlled rolling; Thermo-mechanical processing

1. Introduction

Pursuit of lowering the production costs of mass-scale metallurgical products with required mechanical and technological properties, especially for plates and selected hot-rolled long products, resulted in a development of integrated production systems. These systems are characterized by a conjugation into one production line the continuous casting of slabs with a liquid core, cutting to a desired length, reheating to a required temperature of plastic deformation, hot-working in multi-stand mills with a given reduction in area, cooling of a product with a controlled rate and cutting to a required length or coiling [1,2]. It is an energy-saving technology taking advantage of the heat remaining in the slabs after solidification to hot-working of steel as well as a heat treatment of products from a properly chosen finishing rolling temperature. It influences also a localization of the integrated line in one technological room at a reduced number of hot-working devices excluding blooming mills and others. Similar technological solutions are developed and implemented for the production of sheets. These technological lines consist of cold rolling, recrystallization annealing, and hot-dip galvanizing [3-6]. A special interest is directed to a production of mass-scale metallurgical products from weldable microalloyed HSLA steels (High Strength Low Alloy) deriving from weldable structural steels. This group of steels formed under properly chosen conditions of hot-working and controlled cooling allows to manufacture metallurgical products of the high strength, susceptible to metal forming operations and good weldability. These features make possible to produce modern constructions, vehicles and machines with the weight selected rationally to a technological capacity. It is connected with the reduced energy consumption and has a distinct influence on decreasing a speed of the production growth of steel as well as limitation of ecological damages caused by the environment-arduous metallurgical industry.

2. Characteristics of low-alloyed steels (HSLA)

Microalloyed structural steels contain to 0.2% C to 1.8% Mn and Nb, Ti and V microadditons with a content of about 0.1%. Sometimes, they contain an increased content of N and up to 0.005% B – increasing hardenability. Taking into account, that metallic microadditions have a high chemical affinity to oxygen, and Ti also to sulfur, these steels are smelted with the use of the secondary metallurgy including deoxidation, desulfurization, a modification of non-metallic inclusions, introduction of microadditions and alloying components, vacuum degassing and continuous casting. When B is used, it is necessary to give Ti to a liquid metal in a concentration indispensable to bond nitrogen as TiN. It limits a possibility of forming the BN nitride in a steel, in a solid state.

The high chemical affinity of metallic microadditions to N and C decides that they are bonded in the austenite in interstitial MX-type phases of regular NaCl-type lattice, where: M – Nb, Ti and V, while X – N and C. If a range of hot-working temperature of steel is selected properly to the kind and content of a microaddition, it results in precipitation of dispersive particles of MX-type phases on dislocations in the plastically deformed austenite and after deformation finishing. Dispersive particles of these phases reduce slightly a rate of statical recovery and recrystallization of austenite in intervals between successive passes and after hot-working but hamper a grain growth of this phase. It leads to forming a fine-grained structure of the austenite, which transforms during cooling into the more fine-grained ferritic-pearlitic structure, having an influence in the increase of yield point of products, proportional to $d^{-1/2}$ (d-grain size). The grain refinement results additionally in lowering the ductile-brittle transition temperature of steel. A comparable influence into strengthening of products has precipitation hardening of steel by dispersive particles of MX-type phases. However, the precipitation process results in increasing the ductile-brittle transition temperature, too [7-11].

The influence of the Nb, Ti and V concentration on a yield point and a change in the ductile-brittle transition temperature T_{27J}, for a low-carbon steel caused by the grain refinement and precipitation hardening shown in Fig.1. It is apparent from Fig.1 that the most effective on the YS increase and lowering the T_{27J} temperature has Nb at a concentration of 0.04% and Ti at a concentration of about 0.08%. The lower effect of Ti compared with Nb is due to a higher temperature of precipitation initiation in the austenite of dispersive TiN and TiC particles. These particles, with decreasing the temperature in successive passes of rolling, coagulate and hamper a grain growth of recrystallized austenite less effectively compared with NbC phases.

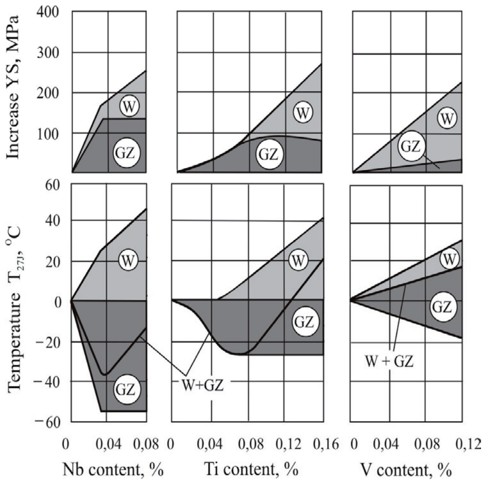

Fig. 1. Influence of the Nb, Ti and V content on the increase of the yield point and variation of the impact transition temperature of low carbon steel [12]: GZ – influence of grain refining, W – influence of precipitation hardening

Whereas, the precipitation of VC carbide occurs near a finishing hot-working temperature of steel. Because of this, its influence on a grain refinement of the γ phase is not to much, but is essential for precipitation hardening. A slightly higher temperature stability has VN. Then, the steels containing the increased concentration of nitrogen are used. The above data indicate that the efficiency of the interaction of microadditions depends on a temperature stability of MX-type phases, which a dissolution (precipitation) kinetics is described by the equation:

$$\log[M]\cdot[X] = A - B/T \qquad (1)$$

where: [M] and [X] weight percentages of the metallic microadditions and metalloid dissolved in the austenite at the T temperature respectively, A and B – constants connected with the enthalpy of forming the given MX-type phase (Table 1).

Table 1.
Values of the constants A and B in the equation (1) for selected carbides and nitrides [17,19]

Phase Const.	VN	VC	TiN	TiC	NbN	NbC
A	9500	7840	8000	10745	8500	7290
B	6.72	3.02	0.32	5.33	2.8	3.04

Equation (1) and the data listed in Table 1 allow to calculate a starting temperature of the precipitation of MX-type phases for a given content of the microadditions introduced into the steel. A knowledge of this temperature is of essential importance for designing hot-working parameters of steel. Problems concerning a development of microalloyed steels are a subject of rich technical literature, numerous scientific conferences and monographs [13-20].

3. Hot-working

Rolled products with a fine-grained structure and high mechanical properties of microalloyed steels are produced by the controlled rolling or thermo-mechanical processing.

3.1. Controlled rolling

Controlled rolling is used for low-carbon steels with the ferritic-pearlitic structure. This process consists in roughing rolling of slabs in an upper temperature range of hot-working, similarly to steels without microadditons, and finishing rolling in a lower range of hot-working. During finishing rolling dispersive particles of MX-type phases in the austenite are precipitated. During the roughing rolling occurs the dynamic recovery and eventually dynamic recrystallization, and in intervals between successive passes – the static recovery and recrystallization and grain growth. After roughing rolling with high reductions in area the strip is laminar water cooled to a finishing rolling temperature with an interaction of MX-type phases precipitated in the austenite. This temperature is usually lower than the recrystallization temperature of the austenite, and even slightly lower than Ar_3 of steel. The product is air cooled from a finishing rolling temperature or more advantageously with the use of accelerated cooling in the $Ar_3 – Ar_1$ range of steel, increasing a density of nucleation places in the $\gamma \rightarrow \alpha$ transformation, and then in the air. In special cases the product is annealed at a finishing rolling temperature for the $t_{0.5}$ time indispensable to obtain 50% fraction of the recrystallized austenite and isothermal quenching is used for attaining the ferritic bainite structure. Designing of mechanical properties of the products is assisted by developed modeled relationships concerning the influence of primary size of the γ phase grains, the temperature and strain rate as well as the degree of deformation realized in successive passes of rolling, on the grain size of recrystallized austenite and $t_{0.5}$ time of this phase – given in the work [19]. A proper selection of hot-working conditions enables to manufacture metallurgical products from this group of steel with the low yield point and 2-3 times exceeding its value compared with a yield point of products manufactured from steels without microadditions of a similar chemical composition.

In case of plates, this technology is possible to realize using the slightly modified integrated ISP (In-line Strip Production) line (Fig. 2), set in motion in 1992 in the ATA Arvedi steelworks, Italy. Its production power is about $5 \cdot 10^5$ t/year. This line includes the continuous casting of slabs with a 60 mm in thickness, burnishing system of slabs with a liquid core to a thickness of 43 mm, shearing machine, three-high roughing train, reheating furnace, Cremona-type furnace with the coiler and decoiler of the strip (a constant temperature is maintained), hydraulic descaler, four-high finishing train, laminar cooling bed and a coiler of the finished product. Replacing in this line the reheating furnace between the roughing and finishing trains by cooling machine of the strip to a temperature of MX-type phases precipitation or lower than a recrystallization temperature of the austenite will make possible to produce in a mass-scale sheets with a thickness of up to 1 mm from microalloyed steels. Suitable to this purpose can by also the following lines FTSR (Flexible Thin Slab Rolling) with a coiler reheated or cooled the strip between roughing and finishing trains as well as TSP (Tippins Strip Process) with the Steckl's mill. The lines are described in the works [1,20]. In relation to long products, for example, I-sections, the CBP (Compact Beam Production) line can be applied.

3.2. Thermo-mechanical rolling

This method is useful to produce weldable plates made of low-carbon toughened alloys steels with B, Ti and Nb microadditions, for example, Weldox 700 to Weldox 1100 of the Svenskt Stäl Company. The plates with a thickness of between 6 to 50 mm, yield point $YS_{0,2}$ from 700 to 960 MPa and impact strength $KV_{-40°C} = 40J$, made of these steels as well as the plates characterized by $YS_{0,2} = 1100MPa$ and $KV_{-40°C} = 27J$ are produced using the conventional rolling followed by toughening. They possess a high anisotropy of ductile properties estimated on a basis of the ratio KV_t/KV_l – transverse to longitudinal specimens.

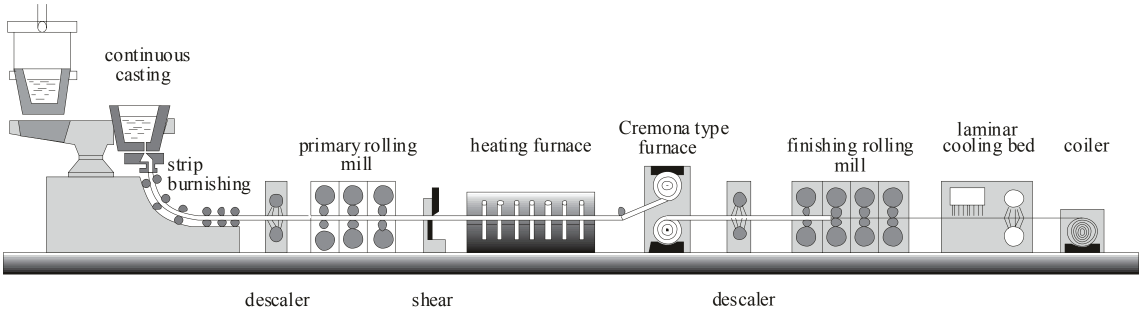

Fig. 2. Schematic diagram of an integrated production line of rolled plates in the ISP (In-line Strip Production) process [1]

Decreasing the anisotropy of the plates can by attained using the thermo-mechanical rolling consisted in multi-pass rolling of the slab in a range of the precipitation of MX-type phases with intervals between successive passes to enable the complete or 50% statical recrystallization of the plastically deformed austenite and isothermal holding the plates at a finishing rolling temperature for the $t_{0,5}$ time before their quenching from this temperature. It this case a heat treatment of the plates is limited to high tempering or to ageing – for steels containing to 2%Cu. A certain problem is the long time required especially between finished passes. It exceeds considerably the cooling time of the strip in the air to a temperature of a next pass. This problem can by canceled by the use of retention shields, decreasing a cooling rate. Meeting these conditions, for example, for the Weldox 960 steel with a $YS_{0,2}$ over 960 MPa ensures increasing the $KV_{-40°C}$ energy up to over 100 J and also the KV_t/KV_l ratio to a value near 0.9 [20,23].

A lack of the complete austenite recrystallization between passes leads to a localization of the deformation with a dynamic recrystallization course and a segregation of MX-type phases and alloying elements in shearing bands propagating along the rolling direction. In this case the plates quenched from a finishing rolling temperature just after the $t_{0.5}$ time, followed by tempering, possess mechanical properties similar to that after conventional rolling and toughening.

The presented technology can be used in a continuous technological line of plates made of microallyed steels including the continuous casting of slabs, thermo-mechanical processing and high tempering or ageing.

4. Conclusions

The above analysis indicates a possibility of the application of presently used integrated technological lines after a certain modification to manufacture mass-scale products, especially plates and selected long products characterized by high mechanical and technological properties made of microalloyed steels using the controlled rolling and thermo-mechanical processing.

Products with the ferritic, ferritic-pearlitic and ferritic bainite structures can be manufactured using the controlled rolling in the lines making possible to adjust a finishing rolling temperature to corresponding to the precipitation process of MX-type phases and even lower than the austenite recrystallization temperature. It requires to introduce a cooling machine of the strip between roughing and finishing trains and a modification of the machine cooling the finished product with a various rate at a given temperature range, from a finishing rolling temperature.

In case of rolling the products made of alloyed steels with microadditions by the use of the thermo-mechanical processing is advisable to use retention shields lowering a cooling rate of the strip. They enable the almost complete austenite recrystallization in intervals between successive passes of rolling and holding the finished product at a finishing hot-working temperature just before quenching for the $t_{0,5}$ time required to forming a 50% of the recrystallized austenite. The discussed technologies call for controlling the continuous casting of slabs, hot-working and cooling the finished products.

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