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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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ALLOY STEEL AND HOT AND COLD ROLLING*
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Technical report: Production of free-cutting steel

Prepared for the Government of Yugoslavia
by the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of Nicolai V. Sidorov, expert in free-cutting of steel

United Nations Industrial Development Organization
Vienna

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Explanatory notes

References to "tons" are to metric tons.

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SUMMARY

The "Boris Kidrič" steelworks located in the town of Nikšić (Yugoslavia) has been producing free-cutting steels since 1966. Prior to October 1977 the steel was smelted in 30-ton open-hearth furnaces.

The technology for smelting free-cutting steel in open-hearth furnaces had been satisfactorily mastered so that the production process consistently yielded free-cutting steels of the prescribed chemical composition; however, their qualitative characteristics, as determined, both at the plant and at the customer's were insufficiently consistent both from melt to melt and within the same melt. When rolled at the plant certain melts displayed inadequate plasticity, revealed in the form of a tendency of the ingots and slabs to laminate during rolling. Defects in the form of hairline surface cracks were discovered in the finished product. Inspection by gradual turning indicated the presence of internal hairline cracks as well. Surface cracking of the same kind was also detected at the customer's. The machinability of the OH free-cutting steels was not identical within the same melt and varied from melt to melt as well.

Electric-furnace steel had fewer surface defects in the finished product, but was judged by the customer to be of inferior machinability. This impairment of the machinability characteristic also came to light indirectly when the steel was subjected to in-plant micro-testing for composition, form and distribution of the non-metallic phase (sulphides) in the finished product, and also because of the non-uniformity of the microstructure. It will be recalled that the composition, form and distribution of the non-metallic phase (sulphides) throughout the steel, and also the non-uniformity of its microstructure, in large measure predetermine the machinability characteristic of free-cutting steels. In addition, one of the most serious deficiencies of the technology used for smelting the free-cutting steels in the electric furnaces was the failure of this technology to ensure reliable and consistent melts of the required chemical composition, specifically with regard to the sulphur content in the finished metal.

It is this insufficiently high and inconsistent machinability characteristic that explains the desire of free-cutting steel users to make their purchases in other countries whose products are superior in this regard.

Because of all these factors, and the economic incentive to produce its own free-cutting steels, Yugoslavia requested UNIDO to provide technical assistance for the production of free-cutting steels at the "Boris Kidrič" steelworks at Nikšić.

Following the expert's arrival at the plant and his study of the production situation, he proposed a new technology smelting for the free-cutting steels in electric furnaces, and also a new heating regime for the rolling of the ingots.

A series of test melts was carried out and the steel was rolled according to the proposed new technology, together with several alternative technological approaches which were necessary in order to study the effect of individual steel-making factors on steel quality. After the quality of the test melts had been studied both at the plant and at the customer's, the most rational option was selected and was subsequently used, in January 1978, for a second series of free-cutting steel melts followed by rolling on a heavy-section mill. Because the expert's stay at the "Boris Kidrič" plant came to an end with the termination of his contract, he was unable to conduct a metallographic analysis of this second series of melts.

The results of the work performed point to the following conclusions:

(a) The proposed new technology for the smelting of free-cutting steels in electric furnaces is not overly complex and ensures reliable melts of the prescribed chemical composition;

(b) The new smelting and rolling technology ensures that in the finished product the steel will exhibit good plasticity and a compact macrostructure;

(c) Once the effects of individual steel-making factors on the quality of the finished product have been thoroughly studied, the new free-cutting steel smelting and rolling technology guarantees characteristics that are typical of high-quality steels;

(d) If the quality problems associated with the free-cutting steels produced at the "Boris Kidrič" plant are to be completely resolved, the research and experimental work that has been begun must be continued;

(e) Considering the duration of the steel-making cycle and the need to conduct experiments jointly with the customer, a far longer period than three months is required to solve problems as complex as the production of free-cutting steels.

I. INTRODUCTION

The machinability of structural steels is improved by including in their composition a number of different additives which have a significant effect on the quantity, composition, morphology and structural distribution of either the non-metallic inclusions (containing sulphur, selenium, tellurium and calcium) or the actual metallic inclusions (lead). During the last 10-15 years steels of this type (simple carbon and alloyed steels) have been increasingly used in many countries of the world, since a steel's machinability is one of its most important technological characteristics in determining the ease and efficiency with which it can be worked.

The machinability of a steel affects such factors as labour productivity, the cost price of the product, the volume of capital investment, and the rate of production.

In determining machinability the basic criteria are the speed of cutting, the effect on the tool, and the purity and dimensional precision of the machined surface. The shape of the chip and the ease with which it can be removed from the cutting area are regarded as an additional machinability criterion.

The purity of the machined surface determines the amount of labour that will be required for subsequent operations and also the quality of the finished parts.

At present there are more than 20 known methods for determining the machinability of metals, but the most reliable, objective and thorough evaluation of this characteristic is the one based on the results of industrial testing performed at the very site where the steel is actually used.

As already noted, steel machinability is greatly influenced by the quantity, composition, morphology and structural distribution of its non-metallic inclusions. In turn, the formation of the non-metallic phase is considerably affected by all the metallurgical reduction and conversion processes, such as the smelting technique and the method used to kill the liquid steel, the regime used in heating the ingots for rolling and for the actual rolling, the conditions under which the semi-finished and finished products are cooled after rolling, and others.

It will be evident from these remarks that lengthy and painstaking research, involving a great deal of experimentation, is required to discover and select the best available technology for the smelting and metallurgical reduction of free-cutting steels.

When developing such a technology, consideration must also be given to the types of metal-cutting equipment used for the machining of the steel in question, the types of cutting tools, and the conditions of lubrication. Good machinability which remains constant within a melt and also from melt to melt is especially important in the mass production of standard parts. Such parts are manufactured on automatic lathes or on automatic production lines. Narrowing the discrepancies in machinability ratings is an important factor contributing to the more effective use of metal-cutting equipment.

With increasing frequency mild sulphurous steel or sulphurous-lead steel is being selected for the manufacture of mass-produced standard items.

The "Boris Kidrič" steelworks at Nikšić specializes basically in the production of free-cutting sulphurous steels, which also account for a substantial portion of this plant's total output.

II. THE MAKE-UP OF THE PLANT AND THE OUTLOOK FOR ITS EXPANSION

The "Boris Kidrič" steelworks was 21 years old on 8 December 1977.

At present the plant relies on the following equipment for its basic production activities:

Steel foundry

The foundry consists of three electric furnaces with a capacity of 15 tons each, one with a capacity of 25 tons (all four designed by the Swedish firm "ASEA"), and one new 60-ton electric furnace manufactured by the United States company "Lectromelt".

Rolling equipment

A " [illegible]0" heavy-section mill;

A "420" [illegible]dium-section mill;

A "280" light-section mill;

A hot-rolling sheet mill;

A cold-rolling sheet mill;

Drawing units and equipment for metal finishing.

At present the "Boris Kidrič" steelworks is engaged in a major renovation and reorganization of its basic production areas involving the replacement of obsolete equipment by new and modern units, and also the building of new areas in which up-to-date equipment is also being installed.

In accordance with this renovation plan, two 30-ton open-hearth furnaces have been dismantled in the foundry and a 60-ton "Lectromelt" electric furnace has been installed. An SKF ladle-degassing unit produced by the Swedish firm "ASEA" is being readied for start-up and operational use. In the new bays which are being added on to the plant, and in place of the open-hearth furnaces, the following equipment is to be installed: an additional 60-ton "Lectromelt" electric furnace, SKF-method metal degassing equipment produced by the Belgian company "Hertey" and a continuous teeming unit produced by the United States firm "Conkast". There are also plans to build gas-purification systems for the electric furnaces, using equipment produced by the United States company "AAF" and already acquired for this purpose.

In connexion with the building of the "950" blooming mill, the plant's casting bay is to be redesigned to make possible the teeming of steel into ingots of up to [illegible] tons. There are plans to build facilities for the delayed cooling of the ingots as well as equipment for the heat-treatment of the metal. In addition, other measures have been planned for increasing labour productivity, upgrading the quality of the steel, and improving the working conditions.

A major programme of renovation and redesign is also under way in the conversion and reduction sector, involving the installation of modern equipment and the construction of additional production areas. As soon as the "950" blooming mill (produced by the Czechoslovak firm "Zdaz") has gone into operation, the "7[illegible]0" heavy-section mill will be taken out, and following the completion of the sizing plant (to be outfitted with equipment from various foreign companies) the old drawing equipment will be dismantled.

Once these plans for renovation and redesign have been carried out, it will be possible to increase substantially the mill's annual volume of production, including the production of bright-drawn steel (mainly in the form of free-cutting steels), which will account for as much as 30 per cent of total production. This is the reason behind the keen interest shown by the management of the "Boris Kidrić" steelworks in the development of a production technology for free-cutting steels which will ensure a high-quality finished product.

III. EXPERIMENTAL PART

Essentials of the problem

The "Boris Kidrić" steelworks, located in the town of Nikšić, Yugoslavia, has been producing free-cutting steels since 1966. Prior to October 1977 these steels were smelted in open-hearth furnaces. The technology for smelting free-cutting steel in open-hearth furnaces had been satisfactorily mastered so that the production process consistently yielded free-cutting steels of the prescribed chemical composition; however, their qualitative characteristics, as determined both at the plant and at the customer's, were insufficiently consistent both from melt to melt and within the same melt. When rolled at the plant certain melts displayed inadequate plasticity, revealed in the form of a tendency of the ingots and slabs to laminate during rolling. Defects in the form of hairline surface cracks were discovered in the finished product. Inspection by gradual turning indicated the presence of internal hairline cracks as well. Surface cracking of the same kind was also detected at the customer's. The machinability of the OH free-cutting steels was not identical within the same melt and varied from melt to melt as well.

In October 1977, a 60-ton electric furnace manufactured by the United States firm "Lectromelt" was put into operation, at the same time that the open-hearth furnaces were dismantled. In anticipation of the need to transfer the smelting of the free-cutting steels to the electric furnaces because of the removal of the open-hearth furnaces, during the period of the end of 1976 and January 1977 the plant conducted a series of free-cutting steel melts in the electric furnaces. The electric-furnace metal displayed fewer surface defects in the finished product, but was judged by the customer to be of inferior machinability. This deterioration of the machinability characteristic also came to light indirectly when the steel was subjected to in-plant micro-testing for composition, form and distribution of the non-metallic phase (sulphides) in the finished product, and also because of the non-uniformity of its microstructure. In addition, one of the most serious deficiencies of the technology used for smelting the free-cutting steels in the electric furnaces was the failure of this technology to ensure reliable and consistent melts of the prescribed chemical composition, specifically with regard to the sulphur content in the finished metal. The difficulty of smelting the free-cutting steel in the electric furnaces to achieve a prescribed sulphur content lay in the fact that in these furnaces the steel was smelted under a layer of basic slag. Unlike working with the open-hearth furnace, it is very difficult when tapping the melt from an electric furnace to keep the metal and slag separate, so that it was impossible to exclude an interaction between the basic slag and the sulphur which entered the ladle. As the sulphur melting loss received in the ladle differed from melt to melt, there was no way of preventing instances of non-standard melts.

Experimental part of the work

Faced with these problems in the production of free-cutting steels at the mill, the expert had to deal with a number of difficult tasks, which may be loosely summarized as follows:

(a) A free-cutting steel smelting technology, using electric furnaces, was to be developed that would ensure consistency in the production of a finished metal having a prescribed chemical composition;

(b) The smelting technology must ensure that the finished metal has a specific ratio of elements in line with their influence on the formation of the non-metallic phase;

(c) Ingot rolling heating regimes and rolling conditions were to be devised that would have a favourable affect on the formation of a non-metallic phase of specific form and size, and also on the distribution of this non-metallic phase throughout the metal;

(d) The free-cutting steel smelting and conversion technology must ensure a metal of good plasticity and an accordingly high final yield;

(e) During the reduction and conversion of the test melts, a determination was to be made of the effect of individual technological factors on the formation of the microstructure in the finished metal.

After the expert had familiarized himself with the equipment of the foundry and reduction areas of the mill and the way this equipment was operated in line with the technology adopted for the production of free-cutting steels, he developed and proposed a new technology for the smelting and reduction of these steels that was designed to achieve the objectives mentioned above. He also proposed a programme for studying the effect of individual technological factors on the quality of the finished product. This research and experimental programme provided for several alternative technological approaches involving the smelting and reduction of test melts to be subsequently checked for quality, as finished steel, at the customer's.

The work programme was discussed with the senior engineering personnel of the foundry and rolling shop and was approved by the management of the mill.

On this basis, and using the technology proposed, a series of four melts of low-carbon free-cutting steel was performed. Several alternative techniques for the killing of the steel during the smelting process were checked out in this series. Later, all the melts were rolled on a heavy-section, medium-section and light-section mill in accordance with the mill's usual production procedure. The final phase was the drawing process. During the rolling process on the heavy-section mill, different ingot heating modes were also tested.

The rolling on the medium-section and light-section mills and the drawing of the steel were performed according to the technology adopted at the plant.

While the test melts were being processed, compliance with the prescribed technological procedures was monitored, the surface quality of the semi-finished and finished product was estimated, the metal was subjected to metallographic testing, and the effect of individual metallurgical factors on final quality was examined.

The concluding phase of the first stage of the programme was the quality-control of metal obtained from the test melts at the customer's.

IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

As a result of the completion of the first stage of this work the following conclusions appear justified:

1. The proposed technology for the smelting of free-cutting steels in electric furnaces is uncomplicated and ensures reliable melts of the prescribed chemical composition - including the sulphur content.

2. The proposed smelting and reduction technology ensures a metal of good plasticity at all stages of the metallurgical process and a high final yield.

3. The new technology ensures that the finished product will have a compact macrostructure and be free of surface defects.

4. The composition and form of the non-metallic phase (one of the principal indicators of quality in free-cutting steels) depend on the method by which the liquid steel is killed.

5. The conditions governing the heating of the ingots for rolling exert a substantial effect on the formation and distribution of the non-metallic phase.

Detailed information on the work accomplished and on the test melt analysis findings are available at the "Boris Kidrič" plant.

As a follow-up to this effort to resolve the plant's problems with the quality of its free-cutting steel, the expert collaborated with the staff technologists in preparing a programme and formulating specific recommendations on how it should be carried out.

Moreover, in addition to the recommendations dealing directly with the problems of free-cutting steel production, the expert prepared and submitted to the plant management further recommendations aimed at upgrading the general technological level of production at the plant.

Workers, engineers and technicians were given direct on-the-job training in the electric-furnace smelting of free-cutting steels according to the new technology, in addition to receiving instructions in the form of consultations and discussions.

Recommendations

A. Specifically regarding the production of free-cutting steels:

1. On the basis of the proposed technology for the smelting and reduction of free-cutting steels at the "Boris Kidrič" plant, it would be desirable to continue the research effort along the following lines:

(a) In order to arrive at a final selection of the best of the alternative technological approaches to the electric-furnace smelting operation (particularly the question of the deoxidation of the steel), there should be continued metallographic studies of the metal, including estimates of the effect of individual technological smelting factors on the form, composition and distribution of the non-metallic phase;

(b) There should be continued study of the effect of the conditions applied in the heating of the ingots and semi-finished steel for rolling, and also the effect of the cooling mode for semi-products and finished shapes in the light-section mill on the formation of the non-metallic phase and the microstructure in the finished product;

(c) In order to determine the extent of the effect of individual technological factors arising in the smelting and reduction of free-cutting steels, there should be provision in the research programme for the separate study of these factors;

(d) Research activities should be carried out in collaboration with the users of the steel;

(e) In order to improve the structural uniformity of the free-cutting steels, the metal in the final shape should be standardized;

(f) A research institute engaged in an appropriate area of activity should be involved in this work;

(g) The proper equipment should be obtained to make possible quality and machinability estimates of free-cutting steel directly at the "Boris Kidrič" steelmill.

B. With regard to production in general:

2. All technological instructions should be collated and assembled in the form of single collections arranged according to metallurgical operations, for example:

Foundry operations

Rolling operations

All other operations.

These collections could contain the standardized instructions for all the technological procedures, as for example: smelting, teeming, cooling, heat-treatment, and all other foundry procedures; heating, clamping for rolling, cooling, heat-treatment, and all other rolling mill procedures. By preparing instruction booklets of this kind, responsible workers could more easily be trained in the efficient management of technological operations.

3. A round-the-clock system should be devised for monitoring compliance with operating instructions in the major areas of the plant (foundry, rolling and sizing).

4. Considering the expected range of products and the fact that the steel is to be teemed into ingots weighing as much as three tons, an analysis should be made of the requirements for delayed-cooling and heat-treating facilities in the foundry and rolling area, so that these facilities might then be built.

5. It would be useful to set up at the plant a single scientific and research centre to undertake comprehensive planning and research activities aimed at solving the problems of improved product quality and of mastering new equipment, new technological processes and a new range of goods.

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