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# Investigation on gas metal arc weldability of a high strength tool steel

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ABSTRACT

In this paper, gas metal arc weldability results of a particular advanced tool steel are presented. Indeed, the study was focused on the weld profile, microhardness and microstructure of the joints. The aim was to identify an appropriate filler material and optimize the process parameter.

The validation of results started with a careful metallographic analysis of the joints, in order to verify that the metallurgical properties of the material were not compromised by the welding process. In the following step, all the non-destructive and mechanical tests, imposed by procedure qualification, were performed in order to have a complete characterization of the joints. For all the wires used, hardness tests highlighted that the use of low heat input and a high number of beads causes an increase in the Heat Affected Zone (HAZ) hardness up to values equal to or exceeding the limits imposed by the European standard on the process qualification. To avoid this problem, it was therefore necessary to adopt high electric parameters and thus high heat inputs. The filler material that gave the best results, in terms of uniformity of mechanical properties, is the rutile flux wire.

## 1. Introduction

Tool steels are mainly used for machining and finishing materials, through operations such as turning and milling, and for mould realization. Because of the strict working conditions to which they are subjected, they must have excellent mechanical properties, such as hardness, toughness, wear and deformation resistance, and it is necessary to maintain these properties even at high temperatures [1].

Special high strength steels for tools are the Toolox® series, produced by SSAB Oxelosund (Sweden). They are quenched and tempered steels, produced with an integrated process, able to guarantee a constant and accurate control of chemical composition. Toolox® is based on the concept of metallurgical low carbon content and rapid cooling during quenching: the result is a steel characterized by a particular morphology and by a much greater toughness compared to steels of similar hardness. These characteristics ensure high wear resistance and an increased productivity rate for tools made with this material, even after long periods at high temperatures [1,2].

These kinds of steels are widely studied concerning their wear resistance and the mechanical characteristics in high temperature processes, including their microstructural modification [1,3–8].

Zhang et al., for example, investigated the microstructural evolutions of a martensitic hot-work tool steel during tempering and service, in order to control the tool lifetime. They also proposed a tempering ratio to describe the evolution of different types of hardness with temperature and time, during the tempering of martensitic steel [3].

Concerning the abrasive wear behavior, Colaço and Vilar studied the relationship between the microstructure of a martensitic stainless tool steel and the abrasive wear coefficient. Their work shows that at lower loads, the material with a microstructure formed of martensite and carbide particles presents the higher wear resistance. On the contrary, at higher loads, a microstructure formed of martensite and 15–25% of retained austenite presents a higher wear resistance [4].

Medvedeva et al. and Firrao et al. correlated the microstructure of tool steels for different applications with both their static and dynamic properties, especially in high temperature conditions [5,6].

Luo et al. in two of their works [7,8] investigated in depth the behavior of non-quenched prehardened steel for a large section plastic mould with particular attention to microstructure and hardness uniformity, machinability and few references to its Tungsten Inert Gas (TIG) weldability. From these studies it could be established that hardness is one of the main features to take into account while considering the machining, including welding, of these materials.

Translating these excellent characteristics from machining tools to other kinds of "tools", such as forks, knives and buckets for earth

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moving machines, its metallurgical, mechanical and wear-resistant characteristics make Toolox® an excellent choice for heavy duty applications, such as high temperature environments. For all these reasons, its use in the manufacturing of these and other welded structures makes for a very interesting possibility.

Furthermore, other high strength steels are effectively welded through gas metal arc welding techniques, and there are several studies in the literature that show the effect of process parameter changing on the quality of the welded joint [9–15].

Lazić et al. in three works emphasize the importance of the selection of the optimal procedure and technology for welding high strength steels, with particular reference to Weldox® 700, developed by the same producer of the Toolox® series. After a detailed analysis of the properties of the base metal and the evaluation of the main aspects related to its weldability, they selected the optimal combination of filler materials, methods and technologies of welding, as well as the conduction of a model and other standard tests, establishing the optimal technology of welding, which was then applied to a very secure welded structure [9–11].

The welding techniques are also largely and effectively employed to "functionalised" steels, for example realizing tool steel hardfacing deposits, as studied by Gualco et al. and by Coronado et al. [12,13]. In this case too, the investigation into welding parameters, heat input and shielding gas is essential to realize a durable deposit.

Magudeeswaran et al. analyzed in detail the effect of welding consumables and processes on tensile, impact and fatigue properties of armour grade quenched and tempered joints fabricated by flux cored arc welding (FCAW) processes. In particular they stated that the use of low hydrogen ferritic steel consumables is found to be beneficial to enhance the tensile properties and fatigue resistance of these steel joints, also compared to the joints fabricated by conventional austenitic stainless steel consumables, which are much more expensive [14,15].

On the contrary, only little information on the weldability of tool steel is reported, because welding processes occur mainly in repair operations [16].

In order to find detailed information about industrial applications of welded components with this particular material, using Gas Metal Arc (GMA) process, a careful experimental campaign was carried out.

In particular, the aim was the identification of an appropriate filler material and the process parameters ensuring the best quality of the joints.

The validation of results started with a careful metallographic analysis of the joints, in order to confirm that the metallurgical properties of the material were not compromised by the welding process.

In the following step, all the non-destructive and mechanical tests, imposed by procedure qualification, were performed to have a complete characterization of the joints and verify industrial applicability.

## 2. Materials and methods

### 2.1. Base metal and filler material

Toolox 33® is a quenched and tempered steel, marked by very low residual stress and good dimensional stability. It offers low carbon content and its production process is marked by a rapid cooling: this leads to a particular carbide morphology which ensures limited wear and high production rate, even after regular use at elevated temperatures. In spite of the elevated hardness, Toolox 33® preserves very high toughness values, especially compared to steels with the same hardness, making it an effective and better choice [1,2].

Fig. 1 shows Toolox 33® martensitic microstructure and Fig. 2 the fine carbide dispersion in its matrix.

Due to the high content of alloying elements, this steel has a carbon equivalent, evaluated with the CEV (Carbon Equivalent Value) index [18,19], which is quite high. The specific casting used for the tests (Table. 1), for example, has a CEV index equal to 0.62, for which some precautions during welding were suggested [2,17,18]:

- preheat temperature of about 170 °C;
- low-hydrogen filler materials (max 5 ml/100 g);
- heat input in order to have $\Delta t_{8/5}$ between 10 and 20 s;
- minimum interpass temperature of 170 °C;
- post-heating treatment of about 200 °C maintained for 120 min.

For the welding tests, 14-mm-thick sheets of Toolox 33® were used for the fabrication of single 'V' butt joint configuration. Table 2 reports the specimen dimensions and the indication of bevel angle and the side edge of root face.

Three types of wire were used as filler material:

- metal cored wire, a tubular electrode that consists of a metal sheath and a core of various powdered materials, primarily iron.
- rutile flux cored wire, which gives a remarkable fluidity to the weld pool and a good finishing of the bead. Its arc stability is quite high and usually the joints are free of spatter and its slag is easily removable. This flux, however, does not provide any purifying action of the weld metal.
- basic flux cored wire, which is filled with iron oxides, ferroalloys of manganese and silicon, silicates and carbonates, especially calcium and magnesium. Fluorite (calcium fluoride) is usually added to make the arc ignition easier. Indeed, calcium and magnesium carbonates are used as purifiers but their melting temperature is quite high [17–19].

As a general statement, filler material with yield strength ($R_{p0,2}$) up to 700 MPa has a CEV index lower than base material while very high yield strength filler materials have CEV index higher than base material. In the latter case, it is necessary to pay attention to the thermal cycle, since this kind of material is sensitive to high interpass temperatures [17–19].

In Table 3, the mechanical properties of the specific filler materials selected are reported. All the data are referred to supplier Inspection Certificate, class 3.1.

**Fig. 1.** Toolox 33® martensitic microstructure, 100×.