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Improved tool wear properties in sheet metal forming using Carbide Steel, a novel abrasion resistant cast material

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ABSTRACT

This work presents a comparative study regarding wear behavior between a novel abrasion resistant cast iron, "Carbide Steel" and a number of conventional tool materials frequently used in the automotive industry. Carbide Steel is basically a high-Cr white cast iron heavily alloyed with cemented carbide. The high chromium content and additional alloying elements like WC, TiC or NbC results in a material containing a large portion of hard, wear-resistant carbides with a composition different from conventional white irons normally used in wear applications. Characteristic properties for the material are: superior as-cast properties, improved wear resistance and hardness. The as-cast hardness of Carbide Steel is comparative to hardened steel but depending on desirable properties of the wear part the alloying content can be varied within a wide range. An interesting aspect of the material is potential for sustainable manufacturing, due to the fact that the critical alloying elements are added in the form of recycled carbide inserts.

The experimental work was carried out in a U-bending test equipment to simulate conditions in a stamping process. One type of sheet material was used and seven different conventional tool materials were evaluated. The selection of tool materials ranged from white cast irons to tool-steels and powder steels.

The wear patterns were analyzed and expressed in percentages of reduction of weight of the test specimens, galling tendency and temperature variations during the experiments. All parameters were correlated to the number of strokes. The press force was measured and a friction coefficient was calculated.

An important conclusion from the experimental work is that Carbide Steel has a significantly higher wear resistance compared to the other conventional tool materials evaluated. Galling is also significantly reduced when using Carbide Steel.

The volume part of carbides and the relative size of the same play a significant role in the process leading to less galling and wear, when using Carbide Steel as a tool material.

1. Introduction

The manufacturing industry, for example, the automotive industry is highly competitive and its customers expect numerous renewals of products and models. Therefore, the long-line production is continuously shortened and new products are introduced on the market more frequently. Future trends in the automotive industry are production series of 50,000–100,000 parts, which means that the total cost of production will be divided on a reduced number of parts. A tool is often very expensive; therefore a reduction of the amount of parts will increase the costs for the product. To reduce the costs of tool dies, alternative tool-materials have to be used.

The traditional sheet-metal forming process, including cast steel die-tools and conventional work materials, has been fairly well established and analyzed. However, there is a demand for new forming processes and manufacturing methods due to the developments and introduction of new alternative sheet-metal materials. A general goal for the manufacturing industries is to reduce the weight of metal parts, batch sizes and lead-times of new products. This has led to a request for low weight/high strength sheet-metal materials and tool-materials suitable for short-run die-tools and for forming parts, for example, in High Strength Steel (*HSS*). New interesting sheet-metal materials are, for example, high strength aluminum, High Strength Steel (*HSS*), Extra High Strength Steel (*EHSS*), magnesium and possibly titanium. These sheet-metals are one strong source for galling, i.e. smear tendencies on the tool surface, and due to the wear characteristics they put new demands on the tool-material.

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Wear-tests are usually carried out with conventional standard methods, such as pin-on-disc or block-on-ring tests, [1–5] and the result can only present the wear behavior of the material under a steady load. Generally it is very difficult to compare these results with the wear appearing in a tool for sheet-metal forming, due to the complex varying load and strain during the forming process. These tool materials would therefore have to be directly investigated in a forming process equipment in which the conditions, both for the tool material and sheet metal, are realistic.

White cast iron with high chromium content is a material widely used in wear applications, however not in the sheet metal forming industry. Many attempts have been made to improve these types of material regarding toughness and wear resistance by adding different alloying elements like vanadium, titanium, neobium etc. to the melt [6]. The main objective to add additional alloying elements is to alter the carbide structure of the material. Size and composition of the carbide contents can also be altered using different solidification rates or heat treatments [7,8]. The size of the carbides and the volume fraction are the most important parameter to obtain wear resistance, although the composition of the surrounding matrix also contributes to the total material properties [9,10]. Work has been done regarding the anisotropy of the overall carbide orientation vs. the abrasive wear resistance in high chromium cast iron [11,12]. The orientation of the carbides in relation to the wear direction can give rise to a noticeable improvement of the wear-behavior if the long axis of the carbides are parallel to the wear direction.

This report shows the results using a novel type of modified high chromium white cast iron, e.g. Carbide Steel as a die-tool material in a sheet-metal forming application in comparison with some conventionally heat-treated tool-steels. The used wear test was the U-bending method in which the conditions are realistic and well correlated to a sheet stamping operation.

2. Carbide Steel

Carbide Steel is a new type of material designed for extreme wear and corrosion environment. The Carbide steel is basically a high-Cr white cast iron alloyed with cemented carbide (13 wt%). The cemented carbide can be added to the base alloy either as powder from cemented carbide tools or through the use of recycled carbide tools. For a sustainable manufacturing system, this last aspect, to recycle worn out carbide tools, is most interesting. The characteristic properties for the material are the castability, and its high wear resistance due to the composition of carbides. The high castability is achieved by modification of the chemical composition of the base alloy. The pronounced wear resistance is the result of the high carbide content, which forms along with austenite during solidification as a proeutectic or eutectic phase depending on alloy composition, and particularly depending upon tungsten, chromium and carbon content. The material can reach as hardness of 61-63 HRC without any heat treatment (as cast).

Carbide Steel has found numerous applications where heavy wear is involved, frequently accompanied by elevated temperature and/or chemical exposure. Potential applications can be found in sheet metal forming processes, crushing and milling segments in the mine and pulp industry, injection parts in plastic industries and other durable parts in the tooling industries exposed for abrasive wear. Wear resistance of the Carbide Steel is primarily governed by quasi-ceramic hard phases such as carbides, embedded in a metallic matrix. Carbide Steel is produced by a modification of a high-alloy white iron alloy by adding cemented carbides (tungsten carbide and Co, WC–Co) to the molten metal. Due to its high carbon content it is per definition a cast iron. Depending on desirable properties of the wear part the content of alloy material can be varied within a wide range. What is common for and a distinctive feature of all these alloy types is however their intense hardness and wear resistance.

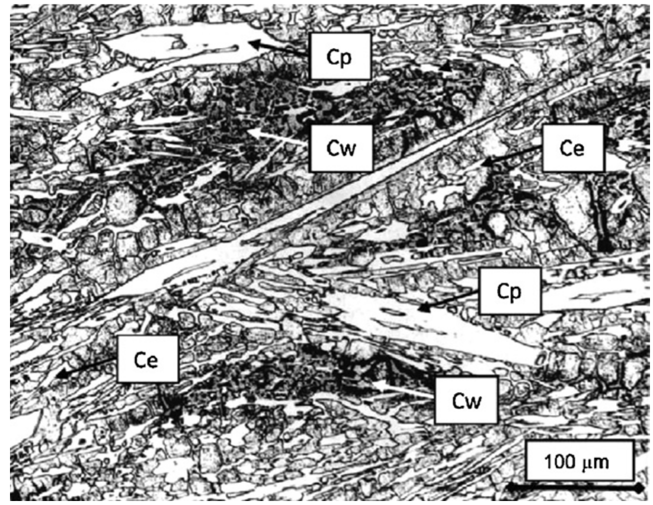

Fig. 1. As-cast microstructure in 50 mm cast section, Vilella's Martensitic etch, ×100. Cp = primary carbides, Ce = eutectic Cr carbides, Cw = eutectic carbides rich in W.

Table 1
Alloying composition of the studied Carbide Steel.

c	Si	Mn	Cr	Ni	Co	W	Fe
2.8%	1.1%	0.25%	25.5%	0.4%	0.8%	7.9%	Rest

The structure is dominated by the characteristic primary carbides, but also eutectic carbides and islands of retained.

The master alloy for a Carbide Steel is a white cast iron with a content of chromium. Tungsten carbide (WC) is added to the melt at a temperature of ca 1600 °C. Using recycled carbide inserts as a WC source, also means that a certain amount of cubic carbides are added to the melt, i.e. TiC, TaC and NbC. At the processing temperature of the Carbide Steel, all added carbides are completely resolved in the molten base alloy, giving a homogenous and single phase melt. At the initial solidification of the melt, the precipitation of primary carbides starts. These carbides are predominantly of complex form, consisting of more than one carbide forming element. This can be explained by the fact that a majority of the alloying elements are strong carbide formers, including the dominant element chromium. At the eutectic temperature, secondary carbides are formed, together with an austenitic matrix.

At later stages of the cooling cycle, at temperatures when the Carbide Steel is completely solidified, additional secondary carbides are formed, providing an additional precipitation hardening effect. In some cases, this can have the practical consequence that a section larger in size shows a higher hardness than a slimmer section, see for example Table 2.

The Carbide Steel can be heat treated through precipitation hardening. The material is heated up to 1040 °C, and afterwards cooled to room temperature. In this process, the matrix is converted from austenitic to martensitic form. No dissolution of previously precipitated carbides has been observed, meaning that these carbides remain in the hardened state. If a lower hardness is required, the Carbide Steel can be annealed in a traditional way.

2.1 Microstructure

The microstructure of the as-cast Carbide Steel is illustrated with the micrographs in Figs. 1–2. This particular alloy has a composition as presented in Table 1.