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# Sustainable machining through increasing the cutting tool utilization

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ABSTRACT

Several previous articles have discussed different approaches to improving sustainability during machining operations. However, more effective utilization of cutting tools is an approach that has been overlooked in previous investigations. Increasing the effectiveness of cutting tool utilization decreases the need for new tools as well as the resources and energy needed to produce new cutting tools. The aim of this study was to maximize cutting tool utilization during machining operations without adversely affecting product quality, thus decreasing the environmental impact of machining operations. This was achieved by determining to what extent it is possible to increase total tool life by using previously worn tools in a secondary machining operation. For both the milling and turning cases investigated, experimental results showed that it is possible to increase the total tool life by approximately 50%–100% compared to equivalent conventional machining operations. The increase in tool life could decrease the production cycle time by approximately 15% and reduce energy consumption by 12% as compared to conventional machining processes.



## 1. Introduction

Sustainable development has received increasing attention in recent years. In 1987 the United Nations defined it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). Such development is needed in all parts of our modern society, including the production process.

The concept of sustainable production emerged at the United Nations Conference on Environment and Development (UNCED, 1992) and has been recognized as a vital component in achieving sustainable development (Jovane et al., 2008). It requires a clear link between technology and economics (Ståhl, 2011). Sustainable development must go hand in hand with technological development in order to become an integral part of the production process. Garetti and Taisch (2012) argue that standards and norms are crucial factors for enabling a faster diffusion of new technological knowledge into modern production. Smith and Ball (2012) emphasize the importance of having a holistic view of the whole manufacturing process in order to be able to identify potential strategies for improving sustainability. Despeisse et al. (2013) present a set of tactics for achieving sustainable production, all of which could be used individually or in combination to increase the sustainability of production processes. Another important factor for obtaining sustainable production, discussed by Duflou et al. (2012), concerns the importance of choosing an appropriate manufacturing method for the specific part being produced. Overall, manufacturers need to evaluate process sustainability in addition to the traditional economic and technical aspects of their operations.

Currently, there is no universally accepted definition of sustainable machining. Often this parameter is described in terms of processes that can result in improvements with regard to such matters as (i) reducing waste, (ii) reducing power consumption, and (iii) enhancing operational safety (Jayal et al., 2010). According to Pusavec et al. (2010), there are several different approaches to improving sustainability during machining operations. For example, the use of cutting fluid is often described as one of the main environmental hazards during machining (Kuram et al., 2013). Thus significant effort has been put into minimizing the use of cutting fluid even when machining difficult-to-machine materials (Shokrani et al., 2012). Another problem that has to be addressed is the quick wear of cutting tools. By optimizing tool life, it is often possible to improve the sustainability of a machining process while reducing the manufacturing cost. However, increased tool utilization may not always result in lowered manufacturing costs. There is a balance between tool life and the cost of both the tool and the machining process to obtain an economical tool life resulting in minimal manufacturing costs (Hägglund, 2002). Moreover, Helu et al. (2012b) caution that an increase in sustainability during machining may sometimes result in a reduced

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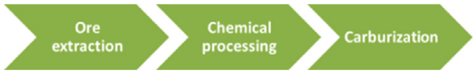


**Fig. 1.** Processing steps for obtaining tungsten carbide.

product quality, which could lead to poor sustainability over the whole product life cycle.

Traditionally, machining processes are optimized by minimizing the manufacturing cost while still complying with technological limitations (Hägglund, 2002). Thus Schultheiss et al. (2012) presented a method for improving the machining process during normal production. But while in some cases, the economic goals correspond to the goal of sustainability, this is not always the case. In order to further consider environmental concerns, Rajemi et al. (2010) proposed a new model that takes process energy consumption into consideration while selecting process parameters during turning. A similar model was developed by Bhushan (2013). Both these models are well suited to improving the sustainability of a machining process.

In an earlier article, Dahmus and Gutowski (2004) stated that the direct environmental influence of tooling is limited. Yet even though the influence of cutting tools on the overall sustainability of a machining process is limited, their influence should not be overlooked. All parts of the process need to be improved as much as possible to achieve truly sustainable machining processes.

## 2. Manufacture and recycling of coated cemented carbide inserts

Coated cemented carbide inserts are manufactured using powder-metallurgy. Tungsten, which is an important part of the inserts, can be obtained from chemical processing of either scheelite ($CaWO_4$) or tungstenite ($(Fe, Mn)WO_4$). After several steps of chemical processing, pure tungsten is obtained. The next step is to obtain tungsten carbide through a process known as carburization (Ståhl, 2012). Fig. 1 briefly illustrates the processing steps for obtaining tungsten carbide. The overall energy requirement during this process is approximately 12 kWh/kg tungsten carbide, if manufactured from ore concentrates (Bhosale et al., 1990).

As illustrated in Fig. 2, the process of manufacturing coated cemented carbide inserts begins by weighing appropriate amounts of the different components. The components are mixed together before being compressed into a green body. This is followed by sintering of the insert, which is a process in which the green body is heated in a protective atmosphere to a temperature of approximately 1400 °C. Sintering eliminates the porosity of the cemented carbide insert. The next step is edge preparation through grinding and lapping of the insert to achieve the insert's final shape. The final step is coating the insert with any of a number of different coatings depending on the desired characteristics.

### 2.1. *Recycling of coated cemented carbide inserts*

There are two main methods of recycling coated cemented carbide cutting tools (Smith, 1994). The first, which involves chemical reprocessing of the cutting tools, is currently used for approximately 35% of all cemented carbide scrap. This process starts with mechanical crushing of the inserts to a powder, which is then treated chemically. The tungsten carbide particles emerge intact and may then be crushed, washed, and dried to form a powder that can be used as raw material for the production of new cemented carbide inserts (Angerer et al., 2011).

The second common recycling method, the Zn-method, in which cemented carbide inserts are treated with molten zinc, is currently used for about 25% of the cemented carbide scrap. Molten zinc creates an alloy with the cobalt binder phase, resulting in an increase in the volume of the binder phase, thereby shattering the carbide structure. The remains can then be crushed to a powder, which is in turn used as raw material when producing tungsten carbide powder for new inserts (Angerer et al., 2011). Depending on the size of the scrap input, the energy consumption for the Zn-method has been reported as approximately 2 kWh/kg of product (Kieffer and Lassner (1994)). The cost of the Zn-method is approximately 20%–35% less than that for other chemical processes, depending on the type of cemented carbide grades being recycled.

Research shows that between 1955 and 1991 approximately 60% of the input tungsten was lost (Kieffer and Lassner, 1994). Since tungsten is a rare and finite resource, these losses could become an increasing concern over time. If the current consumption of tungsten continues, Seco Tools estimates that resources will be depleted within 40–100 years. By recycling cemented carbide scrap it may be possible to delay the time before the resources are depleted by approximately 35%, while also reducing $CO_2$ emissions by approximately 40% (Seco Tools, 2010).

If tool utilization could be increased by 100%, a significant amount of resources and energy could be saved. Fig. 3 illustrates the savings. A possible method for achieving this increase in tool life is discussed in the next section.

## 3. Increasing cutting tool utilization

As discussed by Helu et al. (2012a), significant improvements in sustainability during machining processes can be obtained by optimizing process parameters. Helu et al. (2012b) prove that these improvements may not necessarily decrease the quality of the machined part. Through minor alterations to the current machining process, sustainability may be improved even further.

During milling and turning operations, cutting tools are commonly used in a way that causes the major cutting edge to wear out, while the wear on the minor cutting edge is comparatively small or almost nonexistent. Tool life could be substantially increased by using the same insert in a secondary machining operation. A change in the tool setup would enable the previously lightly worn minor cutting edge to be used as a "new" major cutting edge. There are already commercial products available based on this principle (Larssons i Bjärred Mekaniska Verkstad AB, 2009), but little research has been published on the effects of using this method on the cutting tool or on the machined surface.

An alternative method on increasing tool life involves what is known as the rotary tool cutting process, which has proven to be applicable to both turning (Armarego et al., 1994) and milling operations (Dabade et al., 2003). A rotary cutting tool has been shown to be capable of machining hard-to-machine materials, such as Ti6Al4V (Lei and Liu, 2002) and other aerospace materials (Ezugwu, 2007). Although the rotary tool cutting process shows great potential, it is limited to the use of round inserts. This leads to the


**Fig. 2.** Processing steps for manufacturing coated cemented carbide inserts (Sandvik Central Service, 1982).