Current Trends in Machinability Research

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ABSTRACT

The manufacturing index of a country relies on the quality of manufacturing research outputs. The emergence of new materials such as composites and multi component alloy has replaced traditional materials in certain design application. Materials with properties like high strength to weight ratio, fatigue strength, wear resistance, thermal stability and damping capacity are a popular choice for a design engineer. Contrary, the manufacturing engineer is novice to the science of machining these materials. This paper is an attempt to focus on the current trends in machinability research and an addition to the existing information on machining. The paper consist of information on machining Austempered Ductile Iron (ADI), Duplex Stainless Steel and Nano-Structured Bainitic Steel. The various techniques used to judge the machinability of these materials is described in this paper. Studying the chip formation process in duplex steel using a quick stop device, metallographic analysis using heat tinting of ADI and cutting force analysis of Nano-structured bainitic steel is discussed.

KEYWORDS

Austempered Ductile Iron (ADI), Chip Formation, Cutting Force, Duplex Stainless Steel, Machinability, Metallography, Nano-Structured Bainitic Steel

INTRODUCTION

In this era of design driven material science where new metals and alloys having advantageous material properties are generated to meet the design requirements. Material modification at microstructure level using heat treatment in order to induce the required material properties satisfying the functional requirement of a design application. It becomes necessary to understand how effectively and efficiently these newly emerging materials can be machined. Almost 70% of the assembled or individual product has got machining involved in it at some stage of its production process (Polishetty, 2012). The materials in discussion in this paper are Austempered Ductile Iron (ADI), Duplex Stainless Steel and Nano-Structured Bainitic Steel (NSBS). Another important factor leading to steady emergence of new materials and alloys is to meet the design requirement of the product to function within the envelope of strict environmental laws. Machining is defined as a production process in which the metal is removed in the form of chips (swarf) by a plastic deformation process. The deformation temperature and the force significantly contribute to the quality of the process. Temperature affects the cutting tool material and the forces effect the power and strength needed to perform the process (G.T Smith, 1989). There are two general ways to machine described so far by researchers-orthogonal and oblique cutting. Orthogonal cutting has cutting edge perpendicular to the direction of cut and oblique cutting involves cutting edge at an acute angle to the tool/work feed direction (Sandvik Coromant, 1994).

DOI: 10.4018/IJMFMP.2016010101
Machinability is defined as the ability of a material to produce acceptable outcomes on machining. Some of the outcomes under consideration are surface texture, power consumed, metal removal rate and tool wear. Generally, machinability is qualitative than a quantitative evaluation of the process. The term machinability assumes significance especially for materials which are problematic to machine (G T Smith, 1995). The common problem experienced in machining are rapid tool wear/tool failure, surface finish off-limits, out of tolerance parts, dimensional inaccuracy, strain hardening due to plastic deformation and lower productivity. Machinability research is carried on to look at ways to reduce the weight of the automotive, aerospace engine and ancillaries by replacing heavy and traditional materials such as steel and grey cast iron with materials having high strength to weight ratio such as ADI and NSBS. Cast iron machining has been noteworthy in establishing metal cutting theories by eminent researchers such as G. Boothroyd, M.C. Shaw, E. J. A. Armarego and R. H. Brown. (Armarego & Brown, 1969; Boothroyd, 1965; Shaw, 1986). With the introduction of new cutting tool materials such as silicon carbide, Polycrystalline Cubic Boron Nitride (PCBN) and ceramics, the cutting tools are able to survive in adverse cutting conditions. The machinery has advanced significantly offering wide range of speeds, array of spindle options and multiple axis machining. The demand for higher productivity, lower manufacturing costs and better quality of products has led to development of high speed machining (Childs, Maekawa, Obikawa, & Yamane, 2000).

Machinability research is a way to find solutions to problems experienced during machining and ensure that the economy and efficiency of the process stays optimum. One of the problems under consideration is strain hardening due to plastic strain. Strain Induced Transformation (SIT) is a common problem experienced during machining of ductile materials or materials having unstable microstructural phases. For a ductile material, micro cracks are developed around the tool/chip interface and these micro cracks initiate the process of strain hardening that leads to adiabatic shearing process. As a result of strain hardening the gross crack extends from the free surface to a point in the shear plane where the rate of strain hardening is greater than crack propagation and leads to arrest of the crack formation process (Shaw, 1986).

Strain hardening through plastic deformation is a common phenomenon in ADI. During machining, plastic deformation results in cold working of the surface layer. The depth of cold worked layer depends on the ductility of the material (Astakhov, 2010). Austempered Ductile Iron (ADI) is a type of nodular, ductile cast iron subjected to heat treatments - austenitising and austempering. The heat treatment gives ADI its unique ausferrite microstructure through which ADI gets its advantageous material properties. Possibly the most significant hurdle for the engineering community to overcome, to fully realize the potential of ADI, is in its successful machining. Whilst machining is conducted prior to heat treatment and offers no significant difficulty, machining post heat treatment is demanding and often avoided. Phase transformation of retained austenite to martensite leading to poor machinability characteristics is a common problem experienced during machining of ADI.

Duplex stainless steels are two-phase alloys generally consisting in equal amounts of α-ferrite and γ-austenite phases as shown in Figure 1. Observing how these phases react under various cutting conditions is significant to further understand the issues in machining such as work-hardening and Built-Up Edge (BUE) formation. The duplex alloy tested in this paper include SAF 2205. Nano-structured bainitic steel is a dual phase material containing alternate layers of bainitic ferrite phase in the nano dimensions and the retained austenite phase. Nanobainite steel is produced by isothermal holding at 200°C or less (depending on its chemical composition) till the bainite is formed followed by the austempering operation (Beladi, Timokhina, & Hodgson, 2009; Bhadeshia, 2010). As the transformation temperature increases the diffusion of carbon from ferrite to austenite phase increases which reduces the carbon concentration gradient ahead of the interface in retained austenite (Caballero & Bhadeshia, 2004; Cabrello, Bhadeshia, & Garcia-Mateo, 2003). It is a newly developed material and thus this paper aims to add to the existing knowledge on this material and its machinability characteristics.
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