Wear 268 (2010) 1045–1052

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

The effect of grain size and hardness of wrought Alloy 718 on the wear of cemented carbide tools

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ARTICLE INFO

Article history:
Received 19 December 2008
Received in revised form 11 January 2010
Accepted 12 January 2010
Available online 25 January 2010

Keywords:
Alloy 718
Superalloy
Microstructure
Machining
Tool wear
Burr

ABSTRACT

The effects of grain size and hardness of wrought Alloy 718 on the wear of cemented carbide tools were examined by measuring the actual progression of wear in a specific transverse turning operation. Four different conditions of the same material from the same batch were studied—fine grain material in the soft, solution annealed state and in the precipitation hardened state, and large grain material in the same two conditions. While flank wear, as expected, correlated strongly with hardness the effect of grain size was much more limited. A striking effect was that of the grain size on the notch wear – one of the limiting factors for tool life – which could be clearly related to the amount of burrs formed in the large grain size material both in the solution annealed and fully precipitation hardened condition. The influence of grain size and hardness on the deformed layer of the work piece material and on the morphology of the chips was clearly visible.

1. Introduction

Alloy 718, developed in the late 1950s, is today by far the most used superalloy, mainly applied in the hot section of turbine machinery [1,2] either as vacuum investment castings or in the various wrought shapes supplied. It is a high strength superalloy capable for long time service at 650 °C—the upper temperature limit for this alloy.

Alloy 718 is a precipitation hardening nickel–iron base superalloy, the chemical composition of which is given in Table 1. The high temperature strength is mainly due to the hardening effects of submicron gamma double prime (γ'') precipitates and also to a minor extent to the effects of gamma prime (γ') precipitates [3,4]. The alloy also contains a delta (δ) phase which does not confer any strength but is important during the metallurgical processing for grain size refinement and control. Molybdenum adds strength by solid solution hardening. MC-carbides (NbC, TiC) and nitrides (TiN), are distributed in the matrix, although limited in both size and number they are still undesirable not the least from a machinability point of view.

Since the machining of Alloy 718 has been found to be a challenging task it has attracted considerable research [5–10]. In almost all of this research the machining has been examined from the manufacturing technology point of view for the improvement of tool materials, geometries and machining parameters as e.g. the cutting speed and feed rate. The main reasons for the machining difficulties are due to its high strength and ductility at high temperatures, the strong work hardening of its austenitic matrix and its low thermal conductivity [11,12]. The material can also adhere and weld onto the rake face of the insert which causes severe notching [11]. Machining of Alloy 718 with cemented carbide tools cannot be done at high speed due to the high temperature and stresses generated in the cutting zone. A study indicates that uncoated cemented carbide tools perform better than coated [8].

One of the few systematic studies of the influence of microstructure on the machining of Alloy 718 is by Schirra and Viens [13], where the metallurgical factors' effects on drilling, milling and turning have been investigated. The conclusions for wrought Alloy 718 are that increased hardness and increased grain size increases wear. Another study made on cast Alloy 718, indicates the opposite, i.e. the material in the solution annealed condition is more difficult to machine than the fully hardened condition [14].

A production environment study, involving two of the authors of this paper, tried to relate tool wear in a specific turning operation to the amount of carbide forming elements [15]. It was found that while there was a correlation between the titanium content and wear, no relationship with the niobium content was evident. However, the chemistry variations within the study were small. This early work also indicated that there is a correlation between grain size and notch wear and this indication merited the more

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doi:10.1016/j.wear.2010.01.017

Table 1
Chemical compositions of actual bar.

Ni	Cr	Co	Fe	C	Mo	Al	Ti	Nb	B	Mn	Si	Cu
Bal	18.36	0.33	17.49	0.04	3.15	0.56	0.92	5.46	.001	0.09	0.05	0.14

systematic study of this effect, presented in this paper. It was also considered to be of interest to examine if such a grain size effect on notch wear could be independent of the hardness.

2. Experimental procedures

2.1. Studied material—heat treatments and microstructures

The main purpose of the present study is to examine the effects of grain size and hardness on tool wear. Material from a single batch was used for all tests to avoid any additional effect of chemistry variations. Grain size could be increased by overheating the original fine grain material in a controlled way to allow for grain growth and thus for the different grain sizes to be used in this study. Discs from a wrought bar with the grain size of ASTM 9 and outer diameter 126 mm were used, with the chemical composition as shown in Table 1. A 21 mm hole was introduced in the centre of the discs to facilitate the turning tests.

The delta phase pin the grain boundaries in the material and by heating above its solvus temperature, 1030 °C, and the grains may grow if there is a grain size fine enough in the material to start with. ASTM 9 is definitely a fine enough grain size for grain growth and also compared with the ASTM 4 size allowed for in the specification for wrought material [16]. Numerous heat treatment experiments were carried out to find out the appropriate heating cycle (temperatures and dwell times) to achieve a suitable large grain size. It was found that heating to 1050 °C during 3 h was adequate to obtain a desired grain growth from ASTM 9 to 3. The material was then used in the either the solution annealed condition or in the fully precipitation hardened condition. The solution annealing heat treatment was carried out at 954 °C with 2 h dwell time followed by water quenching to avoid any uncontrolled hardening of the material which may occur if the cooling is too slow. The thickness of the discs used in the turning tests (see Fig. 2) was therefore limited to 40 mm to eliminate any concern for hardness variations across the thickness. For the material in the fully precipitation hardened state a standard two stage precipitation age hardening cycle was subsequently used with the first stage at 718 °C for 8 h followed by furnace cooling to the second stage at 620 °C with 10 h hold time.

Table 2
Grain size and hardnesses.

Material	Grain size [ASTM]	Average diameter [μm]	Hardness [HV]
Large grains solutioned (LG S)	3	127	170
Large grains aged (LG A)	3	127	430
Small grains solutioned (SG S)	9	16	250
Small grains aged (SG A)	9	16	445

In the turning tests, material from the same batch with two different grain sizes and two different hardness levels were used. In Table 2 the actual grain sizes and hardnesses obtained are presented and the corresponding microstructures are shown in Fig. 1.

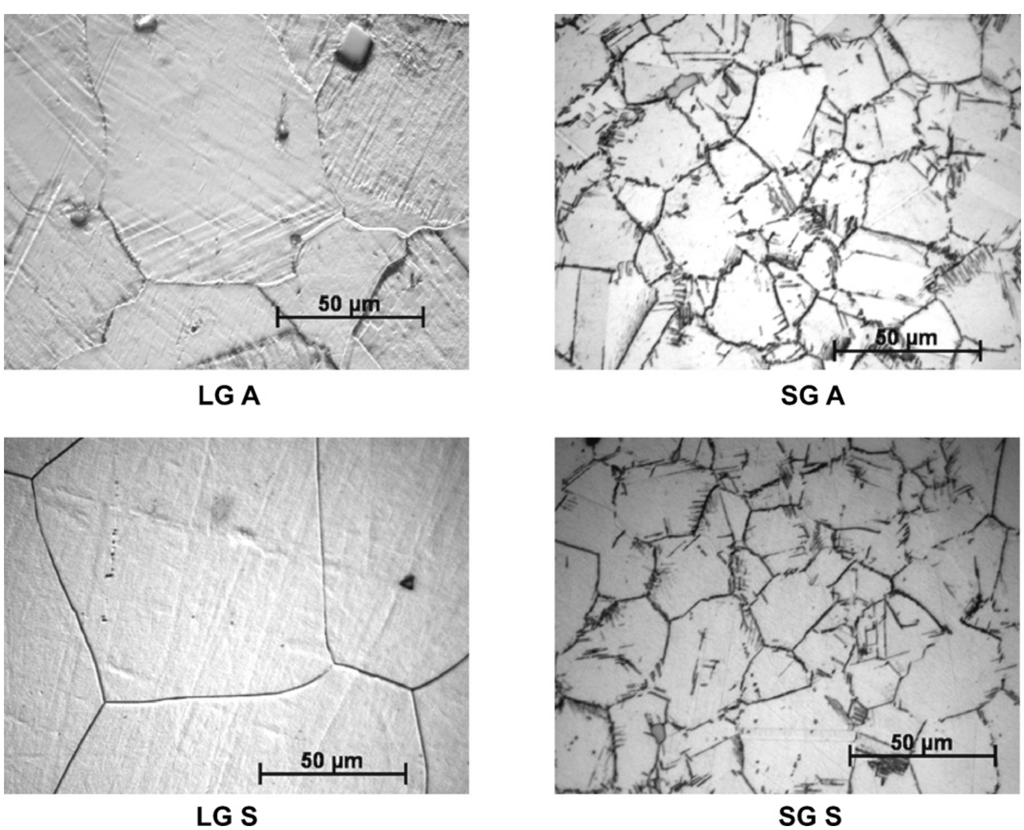

Fig. 1. Microstructure obtained by the different heat treatments.