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Sintering Behavior and Mechanical Properties of High Speed Steel Powder Processed In Nitrogen-Based Atmosphere

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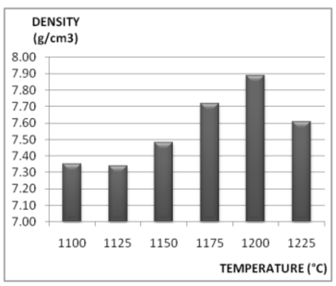
Graphical abstract



Abstract

High speed steel (HSS) is a common material used in the manufacturing of cutting tool and other cutters. In this study, M3/2 HSS had been used to produce cutting tool insert through powder metallurgy (PM) route. The HSS was mixed with iron phosphorus (Fe_3P) powders in a tubular mixer for 30 minutes by dry blending. The powder was compacted at pressure of 632 MPa (16 ton) and sintered at temperature range between 1100°C and 1225°C under nitrogen-hydrogen atmosphere. Further work was done through heat treatment process involving austenitising and tempering to improve the mechanical properties of the insert. The properties were determined through hardness testing and transverse rupture strength (TRS).

Keywords HSS, Cutting tool insert, powder metallurgy

1.0 INTRODUCTION

The adaptation of cutting tools to the requirements of dry machining includes the optimisation of manufacturing technologies, the development of cutting materials of sufficient toughness and high hot hardness, the design of tool geometries as well as the coating of tools [1]. High speed steels (HSS) are more specifically used as cutting tools and wear parts. More recently, these materials have also been used for structural applications. In general terms, for these structural applications, a combination of high strength, wear resistance and hardness together with an appreciable toughness compared with other materials used as tools and fatigue resistance is required [2]. Conventional manufacturing processes for the production of components with these materials include wrought metallurgy and powder metallurgy (PM).

HSS take their name from capacity to retain a high level of hardness when cutting metals and other materials [3]. HSS are used extensively for cutting and forming tools, as well as for wear parts because of superior mechanical properties and abrasion assistance [4]. The most popular compositions of conventional HSS can be divided into two groups according to British Standard: the AISI T series (tungsten based) and the AISI M series (molybdenum based). The characteristics of each HSS grade are due to the alloying elements that enter its composition [5]. Each one contributes in a different manner to the final properties through their effects on the type of carbides produced; their volume fraction and the influence elements have on the heat treatment response [3], [4]. The basic alloying elements of HSS include sufficient carbon to promote the formation of primary carbides plus chromium (Cr), tungsten (W), molybdenum (Mo), vanadium (V) and cobalt (Co) [3], [4]. Tungsten and molybdenum mainly contribute to the formation of primary M_6C carbide and vanadium help to produce the harder, but less soluble, MC type carbide phase.

2.0 EXPERIMENTAL PROCEDURE

In this study, M3/2 HSS were used to produce the cutting tool insert. The powders were weighed based on the formulation 100 g HSS and 9 g iron phosphorus (Fe_3P). All powders were mixed by dry blending using Turbular Mixer at a speed of 57 rpm for 30 minutes. This period of time was used to provide a homogeneous mixture and to incorporate the additive content. Over mixing could change the particle shape of the powders and hence increase the apparent density of the mix. Previous investigations have shown that such times were adequate for producing satisfactory mixing in HSS [6].The idea to add Fe_3P in steel powder was to reduce sintering temperature. Green compacts were produce from the powder by pressing in a single acting die at a pressure of 632 Mpa (16 Tons) to form square blanks, 15 x 15 x 5mm using Automated Hydraulic Press Machine. Compacts green densities were all greater than 70% of theoretical and were calculated by mean of geometric density. Densities were calculated in g/cm^3 using the relationship $\rho=M/V$, where M is the mass of the specimen (g) and V is the volume (cm^3).

The compacted powders were sintered for 1 hour at a temperature range between 1100 and 1225°C. The sintering process took place in a tube furnace under nitrogen-based (95%N_2+5%H_2) atmosphere. The starting heating rate was 5°C/min up to 450°C, followed by 10°C/min for the rest of the sintering process. The samples were slowly cooled to room temperature after sintering process had completed

The sintered samples were heat treated to improve the mechanical properties of the insert. Conventional hardening is the first step in achieving the final properties of HSS. This treatment consists of austenitisation at high temperature, usually below the solidus in order to dissolve enough carbide, followed by quenching. Heating up to the austenitising temperature must be carefully done in order to prevent thermal shock which causes development of internal stresses and arts may cracks or wrap, since sections having different dimensions heat up at different speeds. In order to aid temperature homogenization, the furnace was heated at preheating stage around 450°C and 850°C, held for 10 minutes before heating at 10°C/min[1] to the austenitising temperature. Preheating at 450°C has made to eliminate moisture and grease from the samples surfaces and preheating at 850°C can minimize distortion. Sintered samples were austenitised at temperature 1100°C, 1150°C and 1175°C under nitrogen atmosphere. After being austenitised, the sintered samples were quenched to ensure transformation to martensite.

After quenching process, tempering must be performed. The tempering cycle for HSS usually consists of heating to a temperature in the range 400 to 600°C and holding for a period for usually around 1-2 hours and cooling to room temperature. In this study, samples were heated three times at temperature 500, 550 and 600°C, each temperature lasting for one hour and intermediate cooling to room temperature.

The densities of the sintered samples were determined by Archimedes method using specific gravity meter. The hardness tests were determined using Vicker Hardness Testing machine with load in the range of 3-10kg. Fracture strengths were determined using INSTRON 4505 Universal Tensile machine in Transverse rupture strength (TRS), using miniature rectangular specimens with span (L) =10 mm. The specimens were metallographic examined using a Scanning Electron Microscopy (SEM). Samples were cut into several pieces and were mounted, ground and polished using 3 µm and 1 µm diamond paste. Prior observation unde SEM, samples were etched with natal reagent which is the mixture of 3% nitric acid and 97% ethanol.

■3.0 RESULT AND DISCUSSION

The mechanical properties of HSS could vary depending on sintering schedule. The sintering process took place in nitrogen-based atmosphere as to reduce optimum sintering temperature compared to vacuum [7]. Besides that, nitrogen-based atmosphere proposed a cheaper, safer and environmental friendly sintering process [8].

A uniform and high density is required after sintering of HSS. Enhance the relationship between sintered densities and sintering temperature is shown in figure 1. The density starts to increase gradually at 1125°C and reach its peak at 1200°C, which are 7.89 g/cm^3. Then, the density starts to reduce after sintering at temperature 1225°C due to sample distortion.

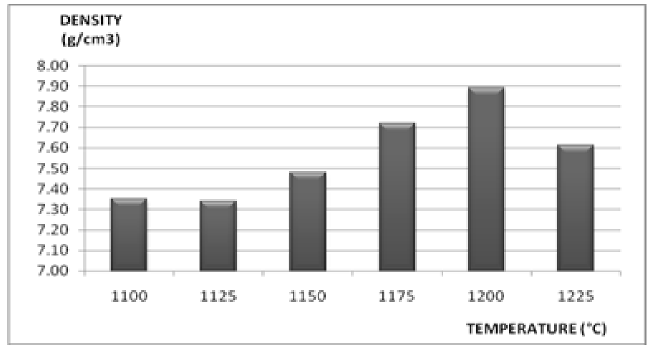


Figure 1 Density of sintered samples at 1100-1225 °C.

Hardness is the important mechanical properties of a cutting tool insert, which provides a measure of resistance to any deformation, fracture or cracking and abrasive wear. The hardness test was determined using the load of 30kg. The indentations for each sample were taken randomly. The HV values were determined as the mean of at least 10 individual measurements.

Table 1 Hardness value

Sintering Temp (°C)	1200	1200	1200	1200	1200	1200	1200	1200	1200
Heat Treatment (°C)	1100	1175	1100	1100	1150	1150	1175	1175	1175
Tempering (°C)			500	600	500	550	500	550	600
Hardness (HV)	**869.8**	**681.1**	**896.5**	**677**	**907.2**	**893.1**	**911.5**	**899.3**	**800.2**

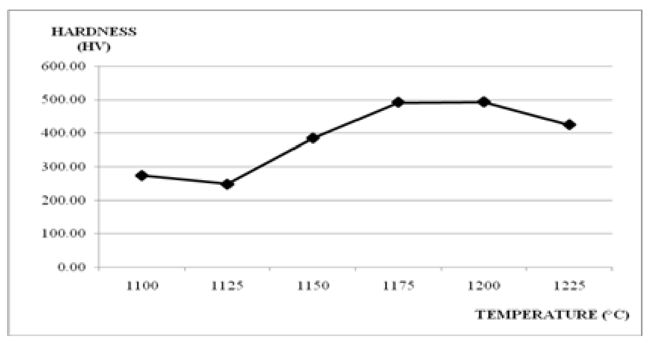


Figure 2 Graph Hardness vs sintering temperature.

Transverse rupture strength (TRS) is closely related to the hardness and fracture toughness. TRS is the stress measured at the breaking point of a material in a standard three point bend test. Based on the figure 3. the TRS value increases gradually from 709MPa at 1100°C to 1490MPa at 1200°C. However, the TRS value drops to 1296MPa at temperature 1225°C.

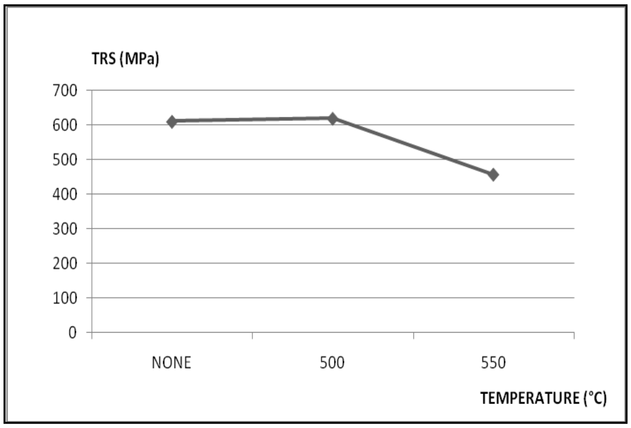


Figure 3 Graph TRS vs temperature

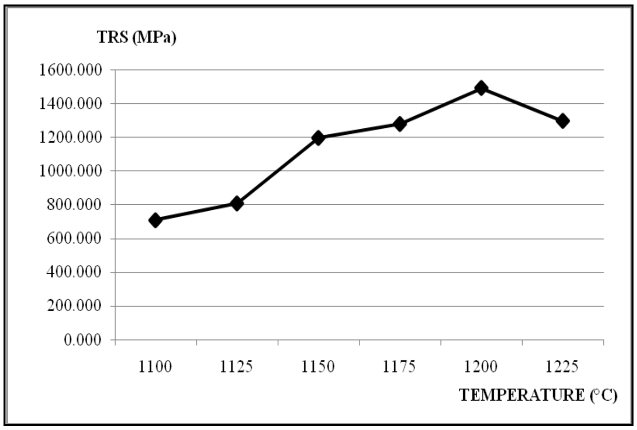


Figure 4 TRS result for sintered sample

■4.0 CONCLUSION

Sintering behavior and mechanical properties of HSS were studied and observed based on different sintering, austenitising and tempering temperature. Generally, the optimum mechanical properties of HSS insert has achieved at sintering temperature of 1200°C. The density at 1200°C is 7.89 g/cm^3 and the value of TRS is 1490MPa. However, the hardness at 1175°C and 1200°C are slightly same. Therefore, 1200°C was the optimum sintering temperature for HSS cutting tool insert. Though, heat treatment process consist of austenitising and tempering must go further research to achieve optimum temperature.

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