

## **A STUDY ON SINTERING BEHAVIOR AND MECHANICAL PROPERTIES OF HIGH SPEED STEEL POWDER THROUGH POWDER METALLURGY ROUTE**

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### **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 ( $\text{Fe}_3\text{P}$ ) powders in a turbula mixer for 30 minutes by dry blending. The powder mixtures were then consolidated into green compact and sintered in the range of 1100 °C – 1225 °C under nitrogen-hydrogen atmosphere. Further work was done through heat treatment process to improve the mechanical properties of the insert. The properties were determined through hardness testing, transverse rupture strength (TRS) and the specimens were metallographic examined using Scanning Electron Microscopy (SEM). Based on the test result, it could be concluded that the optimum temperature for sintering process of M3/2 HSS + 9%  $\text{Fe}_3\text{P}$  is 1200 °C.

*Keywords: High speed steel; cutting tool insert; powder metallurgy;*

### **INTRODUCTION**

Dry machining is one of the ways to achieve a reduction of cooling lubricants, as well as reduced environmental pollution and lower health risk to workers. This leads to higher mechanical and thermal loading on cutting edges. 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 [2].

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 [3]. Conventional manufacturing processes for the production of components with these materials include wrought metallurgy and powder metallurgy (PM). The majority of PM HSS is produced by hot isostatic pressing (HIP) of spherical gas atomised powders [8]. Alternatively,

cheaper irregular water atomised powders can be processed by cold compaction in rigid dies or by cold isostatic pressing (CIP) followed by batch vacuum sintering to nominally 99.5-100 % theoretical density [9].

HSS take their name from capacity to retain a high level of hardness when cutting metals and other materials [6]. HSS are used extensively for cutting and forming tools, as well as for wear parts because of superior mechanical properties and abrasion assistance [7].

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 [10]. 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 [6], [7]. The basic alloying elements of HSS include sufficient carbon (C) to promote the formation of primary carbides plus chromium (Cr), tungsten (W), molybdenum (Mo), vanadium (V) and cobalt (Co) [6], [7]. 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.

## EXPERIMENTAL METHOD

Nominal chemical compositions of some HSS used for this study are shown in Table 1. In this study, M3/2 HSS were used to produce the cutting tool insert. The powders are weighed based on the formulation 100 g HSS and 9 g iron phosphorus ( $Fe_3P$ ). All powders were mixed by dry blending using Turbula Mixer at the 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 [11,12]. The idea to add  $Fe_3P$  in steel powder was to reduce sintering temperature.

Green compacts were produced 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 5 mm 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 temperature in the range of 1100 to 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. After the sintering process is completed, the samples are slowly cooled to room temperature. The sintering cycle is as shown in Figure 1.

Table 1: Nominal composition (wt %) of several HSS

| Spec  | C    | Cr  | Mo  | W    | V   | Co   | %Fe  |
|-------|------|-----|-----|------|-----|------|------|
| T1    | 0.7  | 4.0 | -   | 18.0 | 1.0 | -    | Bal. |
| T6    | 0.8  | 4.0 | -   | 20.0 | 1.5 | 12.0 | Bal. |
| T15   | 1.5  | 4.0 | -   | 12.0 | 5.0 | 5.0  | Bal. |
| T42   | 1.3  | 4.0 | 3.0 | 9.0  | 3.0 | 9.0  | Bal. |
| M2    | 0.85 | 4.0 | 5.0 | 6.0  | 2.0 | -    | Bal. |
| M3/1  | 1.05 | 4.0 | 5.0 | 6.0  | 2.4 | -    | Bal. |
| M3/2  | 1.20 | 4.0 | 5.0 | 6.0  | 3.0 | -    | Bal. |
| M35   | 0.9  | 4.0 | 5.0 | 6.0  | 2.0 | 5.0  | Bal. |
| M42   | 1.05 | 4.0 | 9.5 | 1.5  | 1.0 | 8.0  | Bal. |
| ASP23 | 1.27 | 4.2 | 5.0 | 6.4  | 3.1 | -    | Bal. |
| ASP30 | 1.27 | 4.2 | 5.0 | 6.4  | 3.1 | 8.5  | Bal. |
| ASP60 | 2.3  | 4.0 | 7.0 | 6.5  | 6.5 | 10.5 | Bal. |

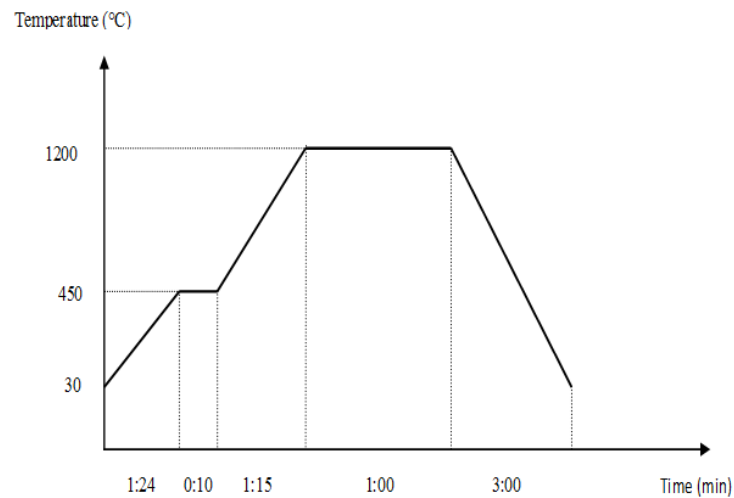


Figure 1: Heating schedule for sintering

The sintered samples were then going through heat treatment process 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. Heat treatment has performed in tube furnace under nitrogen atmosphere. Heating up to the austenitising temperature must be carefully done in order to prevent thermal shock which causes development of internal stresses and parts may cracks or warp, since sections having different dimensions heat up at different speeds. In all cases 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<sup>1</sup> to the

austenitising temperature. Preheating at 450 °C is done so as to eliminate moisture and grease from the samples surfaces and preheating at 850 °C can minimize distortion. Sintered samples are austenitised at temperatures: 1100 °C, 1150 °C and 1175 °C under nitrogen atmosphere. The austenitising cycle is shown in Figure 2. After being austenitised, the HSS are quenched to ensure transformation to martensite. The quenching medium being used in this study is oil.

After the 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 of usually around 1-2 hours and cooling to room temperature. In this study, samples were triple tempered at 500, 550 and 600 °C, each temperature lasting for one hour and intermediate cooling to room temperature. The tempering cycle is shown in Figure 3.

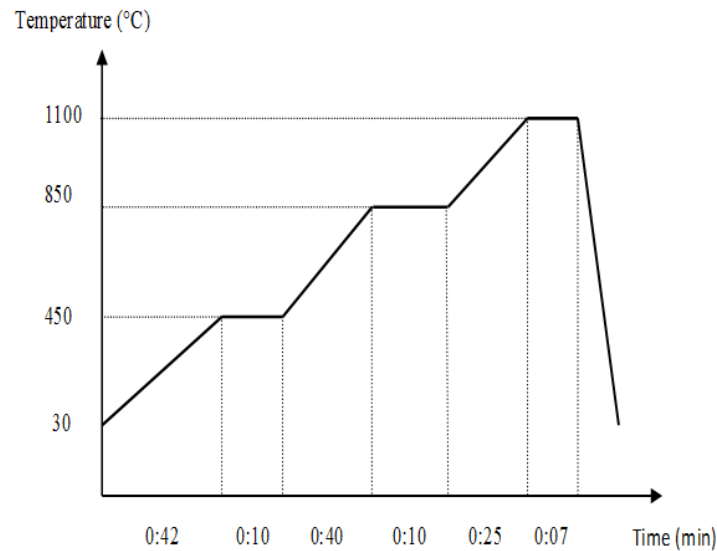


Figure 2: Heating schedule for austenitising

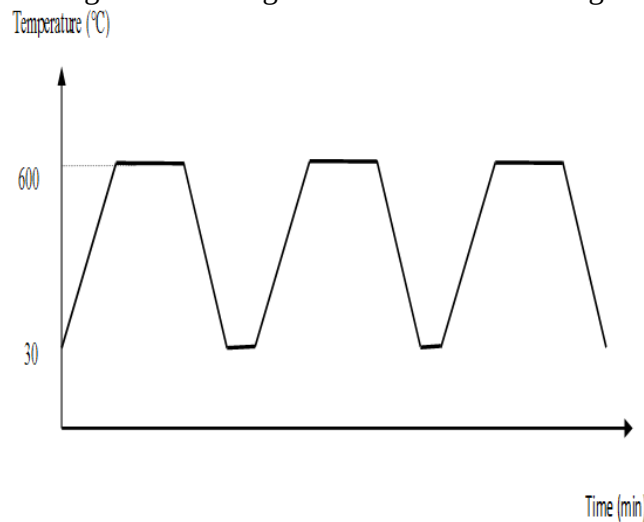


Figure 3: Heating schedule for tempering

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 3-10 kg. Fracture strengths were determined using INSTRON 4505 Universal Tensile machine in Transverse rupture strength (TRS), using miniature rectangular specimens with span (L) =10mm. The specimens were metallographic examined using Scanning Electron Microscopy (SEM). Samples were cut into several pieces and were mounted, ground and polished using 3  $\mu\text{m}$  and 1  $\mu\text{m}$  diamond paste. Samples for the metallographic examination were etched in nital reagent which is the mixture of 3 % nitric acid and 97 % ethanol.

## RESULTS AND DISCUSSION

The mechanical properties of HSS could vary depending on sintering schedule. A uniform and high density is required after the sintering of HSS. Further works have been done through heat treatment to make increase properties of sintered sample. Relationship between sintered densities and sintering temperature is shown in Figure 4. The density starts to increase gradually at 1125  $^{\circ}\text{C}$  and reach its peak at 1200  $^{\circ}\text{C}$ , which are 7.89  $\text{g}/\text{cm}^3$ . Then, the density starts to reduce after sintering at temperature 1225  $^{\circ}\text{C}$  due to sample distortion.

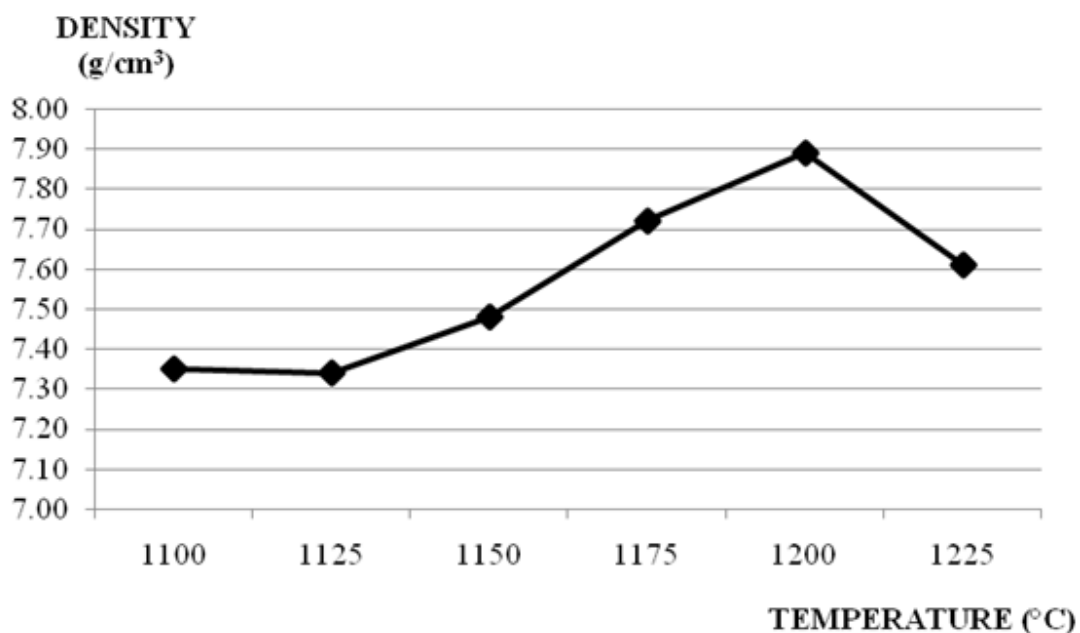


Figure 4: Density of sintered samples at 1100-1225  $^{\circ}\text{C}$

SEM micrographs of sintered sample at different tempering temperature observed under 1kx, 5kx and 10kx magnification using secondary electron image are as shown in Figure 5 to 13. Figure 5, 6 and 7 showed that HSS samples sintered at 1175  $^{\circ}\text{C}$  has more porosity compared to other samples. Figure 8, 9 and 10 showed samples sintered

at 1200°C. Figure 11, 12 and 13 showed samples sintered at 1225 °C displaying oversintered microstructures.

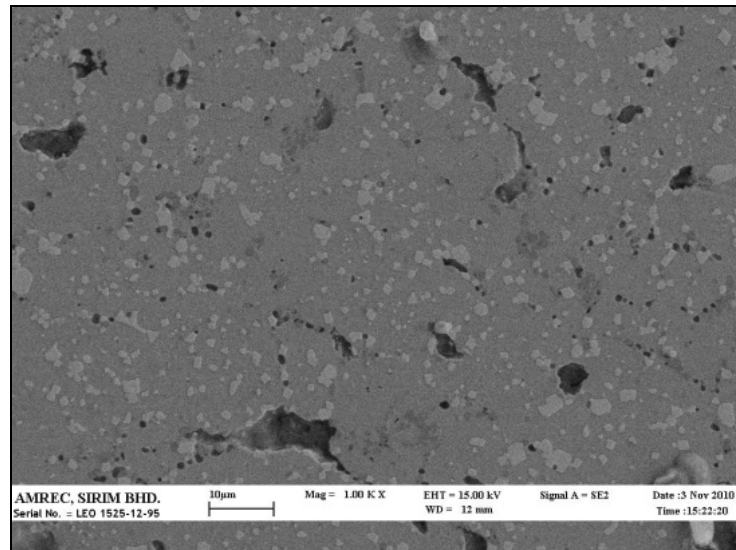


Figure 5: SEM micrograph of HSS samples sintered at 1175 °C at 1kx

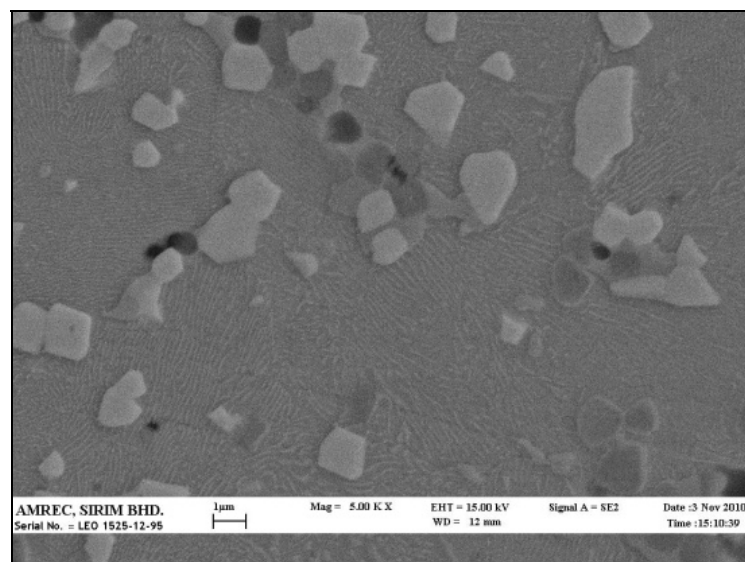


Figure 6: SEM micrograph of HSS samples sintered at 1175 °C at 5kx

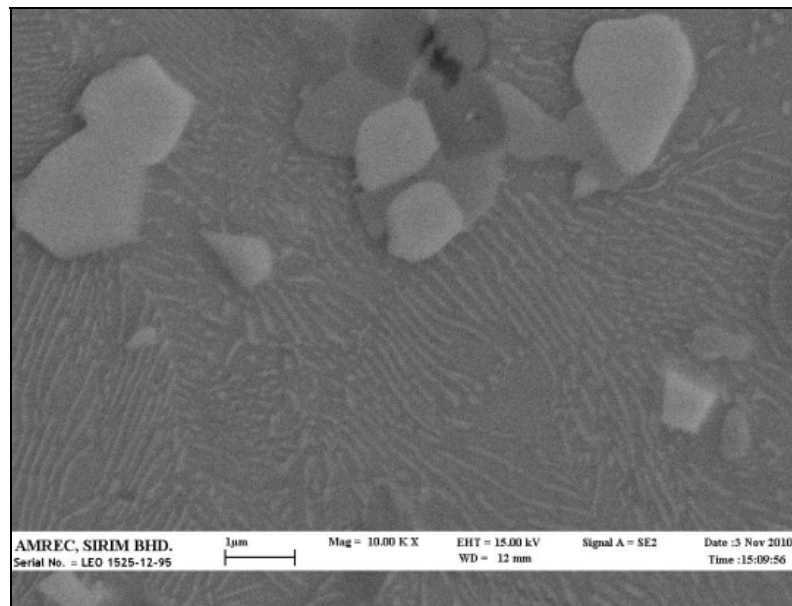


Figure 7: SEM micrograph of HSS samples sintered at 1175 °C at 10kx

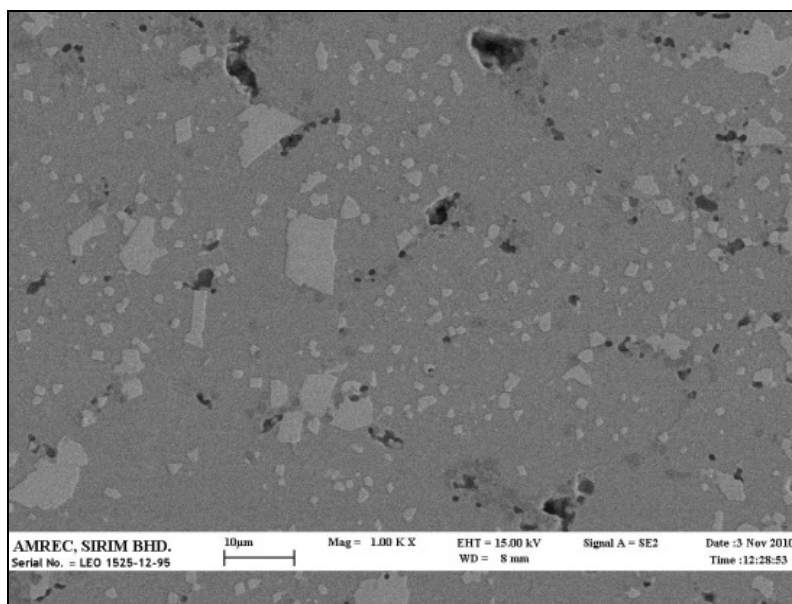


Figure 8: SEM micrograph of HSS samples sintered at 1200 °C at 1kx

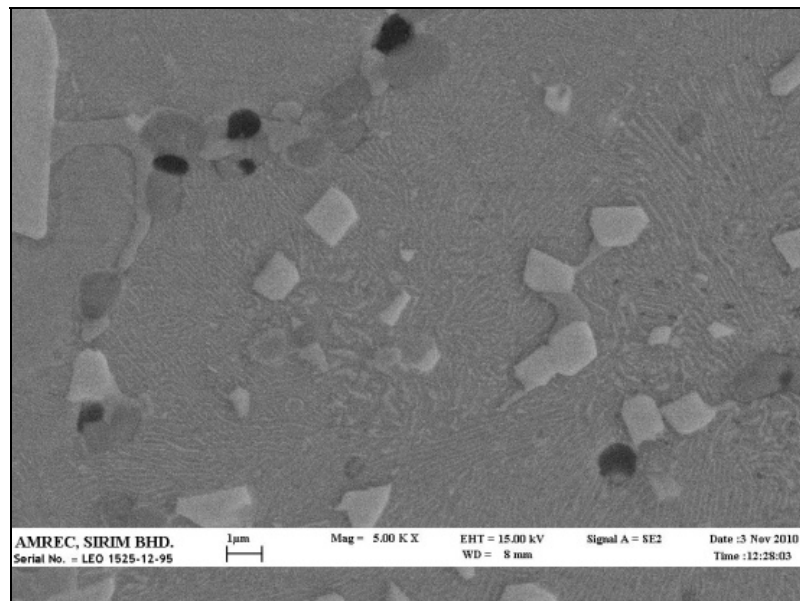


Figure 9: SEM micrograph of HSS sample sintered at 1200 °C at 5kx.

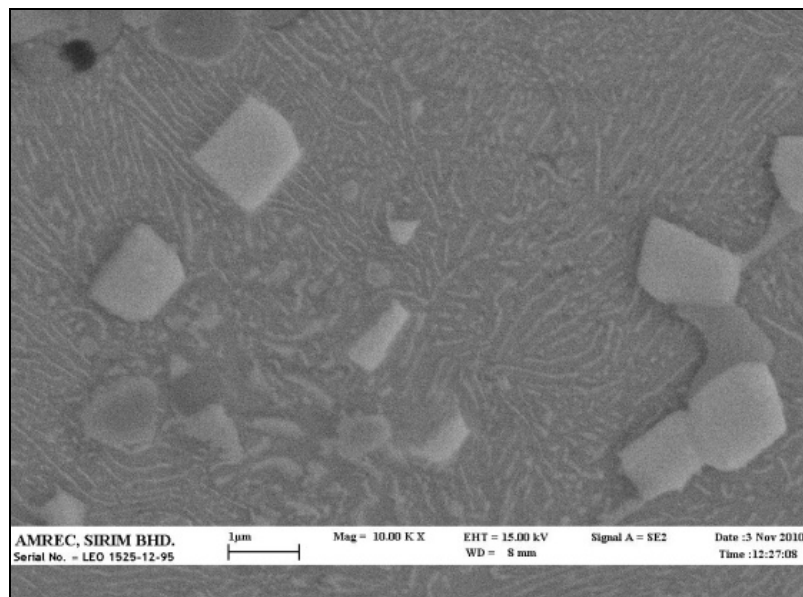


Figure 10: SEM micrograph of HSS samples sintered at 1200 °C at 10kx

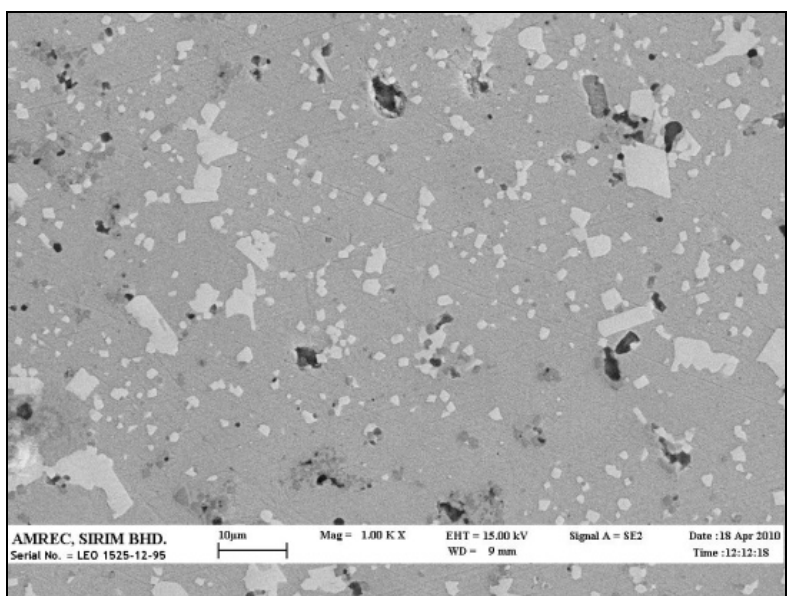


Figure 11: SEM micrograph of HSS samples sintered at 1225 °C at 1kx

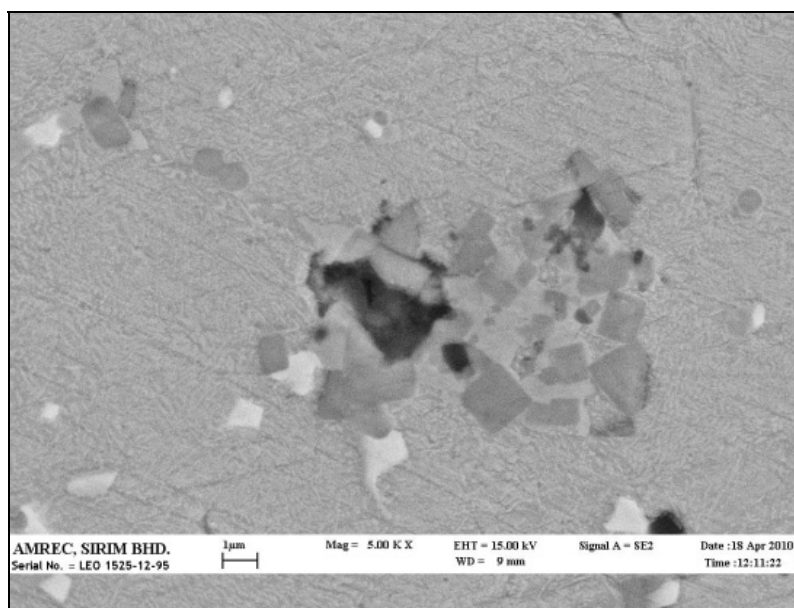


Figure 12: SEM micrograph of HSS samples sintered at 1225 °C at 5kx

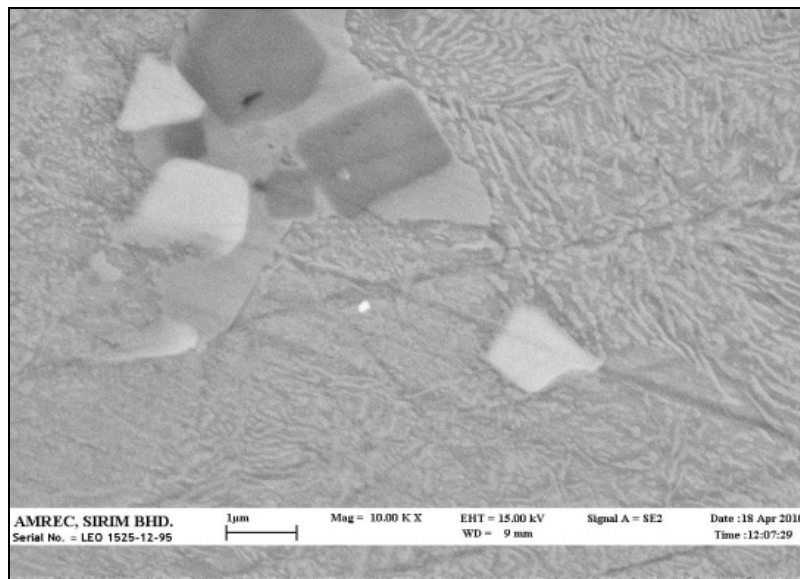


Figure 13: SEM micrograph of HSS samples sintered at 1225 °C at 10kx

Hardness is an 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 tests were determined using Vicker Hardness Testing machine. The load used for the hardness test of all samples was 30 kg. The indentations for each sample were taken randomly. The HV values were determined as the mean of at least 10 individual measurements. The results of the Vickers hardness for sintered samples at range of 1100-1225 °C are shown in Figure 14 The hardness increases significantly from 248 HV at 1125 °C to 493 HV at 1200 °C. However, the hardness drops at 1225 °C.

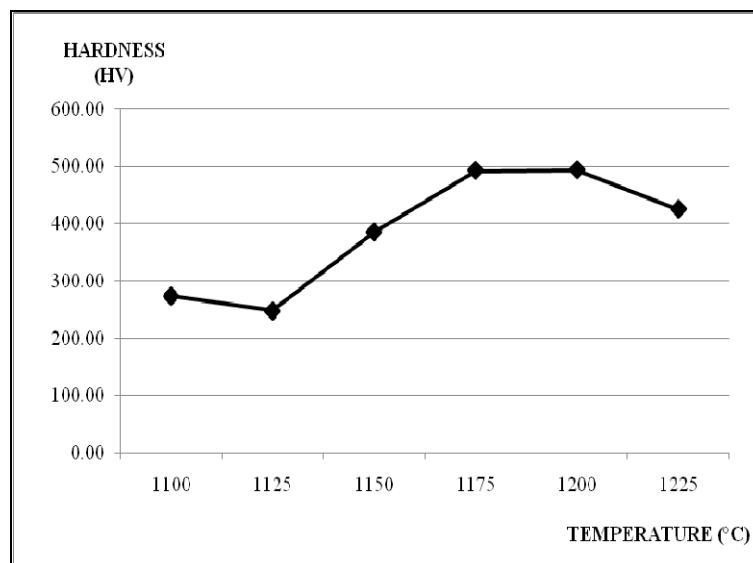


Figure 14: The relationship between hardness and sintering temperature

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. The results of the transverse rupture strength are shown in Figure 15. Based on Figure 15 the TRS value increases gradually from 709 MPa at 1100 °C to 1490 MPa at 1200 °C. However, the hardness drops to 1296 MPa at temperature 1225 °C.

Figure 16 shows the relationship between TRS and tempering temperature. The specimens were sintered at 1200 °C and austenitised at 1100 °C. The samples were tempered at 500 and 550 °C. Figure 17 to 19 show SEM microstructures of tempered HSS samples at 500 °C. Further study must be done to achieve optimum result.

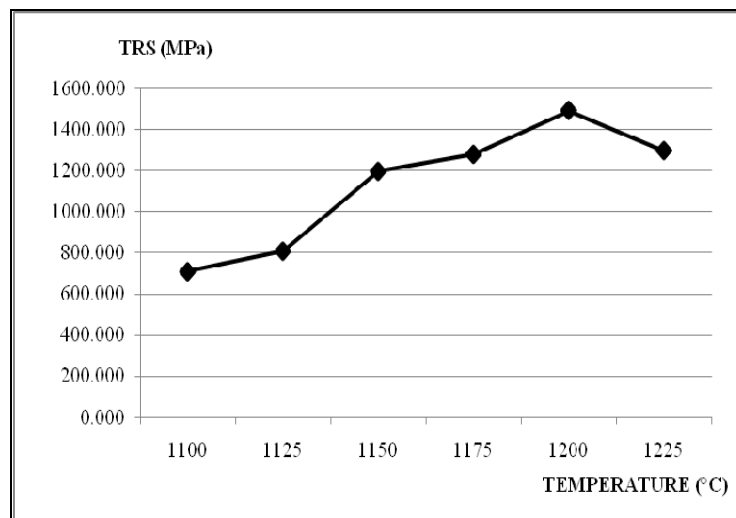


Figure 15: The relationship between TRS and sintering temperature

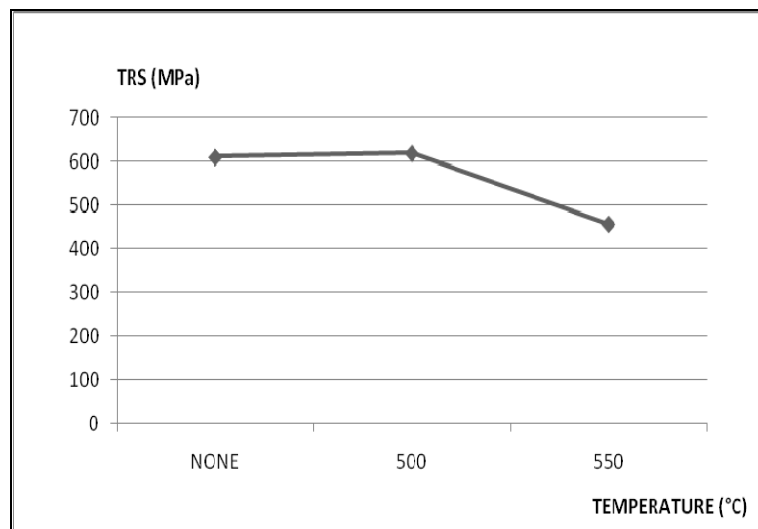


Figure 16: TRS result for sintered sample at 120 °C and austenitised at 1100 °C

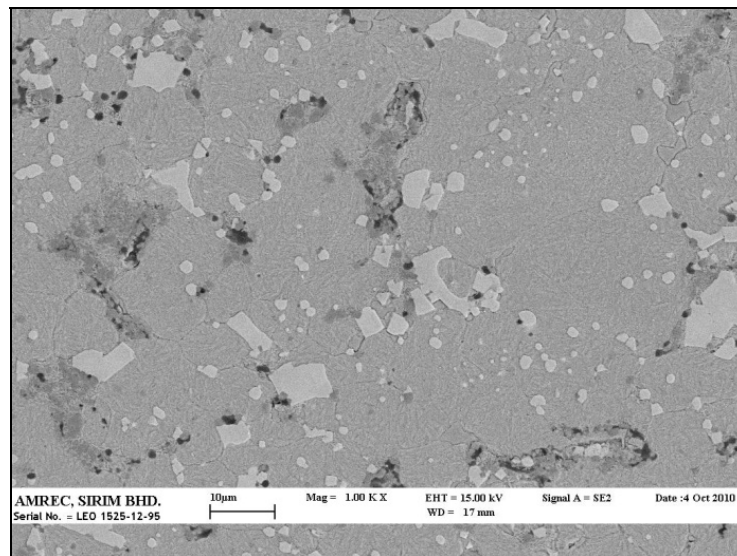


Figure 17: SEM micrograph at 1 kx of HSS samples sintered at 1200 °C, austenitised at 1100 °C and tempered at 500° C

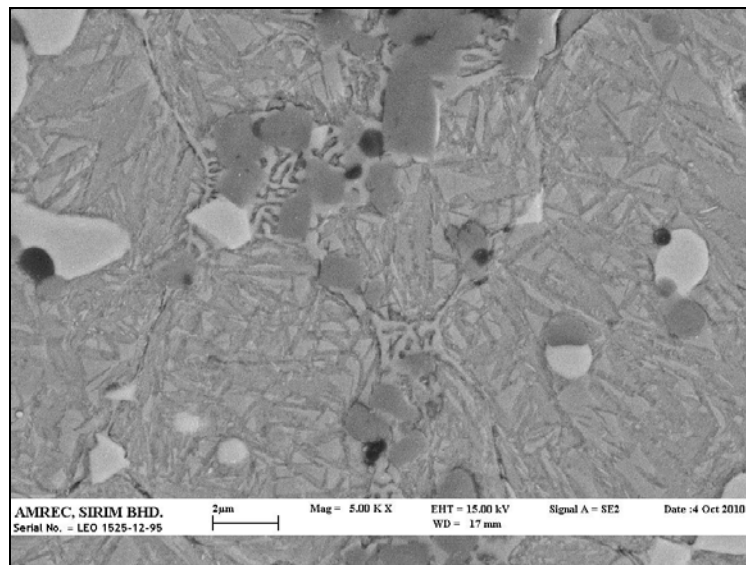


Figure 18: SEM micrograph at 5 kx of HSS samples sintered at 1200 °C, austenitised at 1100 °C and tempered at 500 °C

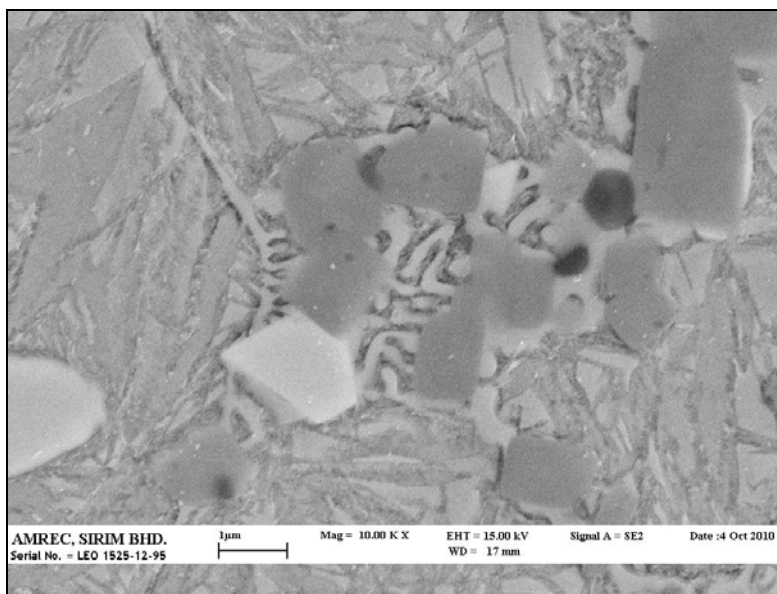


Figure 19: SEM micrograph at 10kx of HSS samples sintered at 1200 °C austenitised at 1100 °C and tempered at 500 °C

### 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 been achieved at sintering temperature of 1200 °C. The density at 1200 °C is 7.89 g/cm<sup>3</sup> and the value of TRS hardness is 1490 MPa. However, the hardness at 1175 °C and 1200 °C are about the same. Therefore, 1200 °C was the optimum sintering temperature for HSS cutting tool insert. The heat treatment process consisting of austenitising and tempering require further research to determine the optimum temperature.

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