Comparative Study of Microstructure and Mechanical Properties of Hot Work Tool Steel SKD 6 with Different Manufacturing Process

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Abstract: SKD 6 tool steel is a medium carbon-alloy steel known as a creep-resisting alloy used as lightweight aluminium (Al) component die casting under high-temperature conditions. SKD 6 tool steel is an imported steel material manufactured by rolling and forging processes. Some studies also developed advance technology to fabricated SKD 6 by recrystallization and partial melting (RAP) process. However, due to the complex geometry and cost efficiency, sand casting method is the most effective method to produce Al dies. The SKD 6 cast alloy sample was heat treated at 850°C for 4 hours and cooled slowly inside the furnace by opening the oven door to 45 degrees. The observation showed that the microstructure of cast SKD 6 is identical to the as-cast product (imported) that has normalized. The microstructure showed that the normalized cast alloy has a ferrite matrix with spherical secondary carbide grain on the grain boundary. However, the hardness value of cast alloy Cr-M-V is slightly lower, 13.6 HRC, while the as-cast alloy is 18.1 HRC. The low hardness value may cause by the lower content of secondary carbides in casting sample, and segregation from secondary carbide. With these results, the imported substitute material is suitable for use.

1 INTRODUCTION

SKD 6 alloy is a medium carbon alloy steel known as a creep-resisting alloy. It is the most common material used in die casting to produce nonferrous materials parts with complex shapes (Hong et al., 2016; Xue et al., 2021). Recently, commercial SKD 6 steels have fabricated through different manufacturing process such as rolling and forging. Some studies also developed advance technology to fabricated SKD 6 by recrystallization and partial melting (RAP) process (Meng et al., 2012). However, due to the complex geometry and cost efficiency, sand casting method is the most effective method to produce Al dies.

Commonly dies are made by machining process from rolling steel Cr-Mo-V. Cr-Mo-V bar/ plate are machining by CNC machine (fig. 1). Though, the machining process increase machine time and the production of scrap, while sand casting process has the advantage of near net shape product. Then, it is carried out using CNC to achieve dimensional accuracy (Adeleke et al., 2022; El-Hofy, 2013).

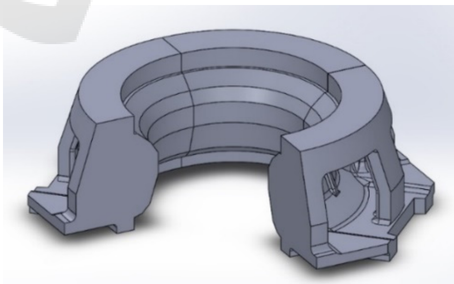

Figure 1: 3D model of dies.

Normalizing shall be given to the as-cast product so that the product can be used under work conditions. Hardness test and metallographic test are

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carried out both from imported and cast alloy Cr-Mo-V steel to get mechanical properties so that meet the specification of industries.

2 METHODS

2.1 Materials and Heat Treatment

In this study, the SKD 6 was produced by sand casting method. Each alloy was melted by using an induction furnace (Inductotherm) with a capacity 250 kg. The casting of SKD 6 material uses metal casting rules, starting from making Y-block patterns, making moulds, and smelting. SKD 6 rolled steel was imported from Buderus Edelstahl GmbH, Bulgaria as a comparison.

Figure 2: Y-Block of Cr-Mo-V.

The compositions of SKD 6 alloy steel were determined according to JIS Standard and being tested by using an Optical Emission of Spectroscopy (OES, ARL 234) before pouring into the sand mould as shown in Table 1.

Table 1: JIS Cr-Mo-V (SKD 6) material standard composition (% W) (International ASM, 2000).

3	Si	Mn	Cr	V	Mo	S	P
0.32-0.42	0.8-1,2	0,5 max	4,5-5,5	0.3-0,50	1,00-1,5	<0,02	<0,03

Normalizing was carried out to refine the grain, improve machinability, eliminate residual stress and improve the mechanical properties of construction carbon steel and low alloy steel (Kristianto, 2018; Roberts et al., 1998). The Y block SKD 6 steel was separated into 2 specimens. the first sample were heat treated at 850 °C for 4 hours and cooled slowly inside the furnace by opening the oven door to 45 degrees while the second were heat treated at 850 °C, held for 2 hours and cooled by air temperature. Last, the all of sample were cut out with the dimension 20x20x10 mm (figure 3).

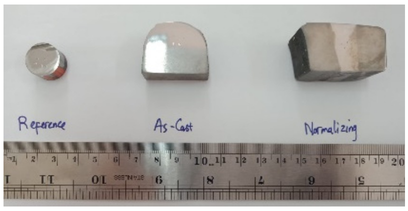


Figure 3: Sample As-recieved (left), As-Cast (middle), Normalizing (right).

2.2 Microstructure Investigations

After the normalizing process, samples were ground and polished with Al_2O_3 paste for the hardness measurements and microstructure analysis. Each sample were polished and etched in 1 g picric acid, 4 mL HCl, 96 mL ethanol. A scanning electron microscope (SEM; Hitachi SU 3500; Japan) was used to examine the microstructure of the SKD 6 steels.

2.3 Hardness Measurement

The hardness measurements were made on a polished surface of sample by using the Rockwell's method. Measurements were conducted on Future Tech Rockwell Hardness Tester Machine with 1.498 N in load and held for 10 seconds.

3 RESULTS AND DISCUSSIONS

3.1 Chemical Compositions

The chemical composition test showed that the sample was confirmed as SKD 6 steels. As Shown in Table 2, the chemical compositions of the specimen are in the range recommended by standard JIS.

Table 2: The chemical composition of specimen Cr-Mo-V cast alloy steel.

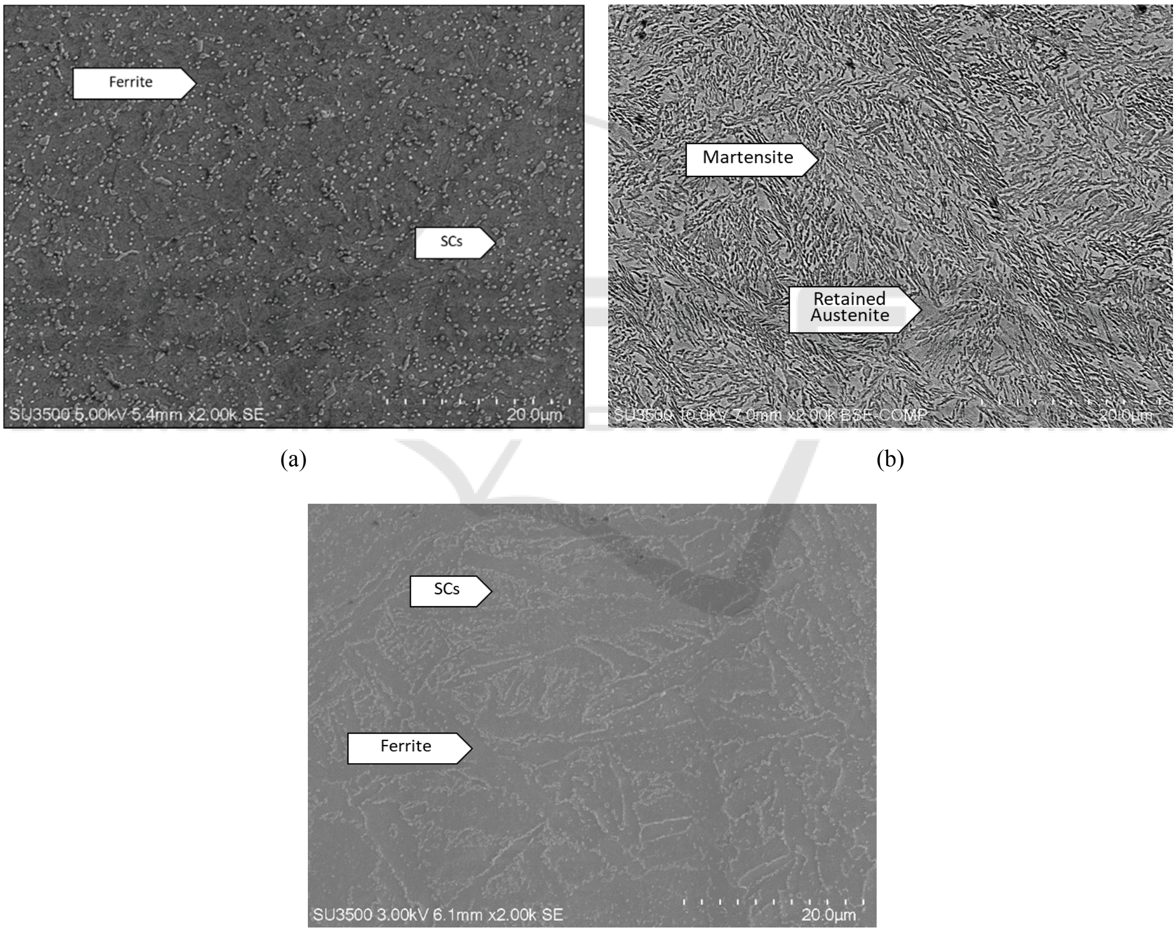
JIS Standard							
C	Si	Mn	Cr	V	Mo	S	P
0.32-0.42	0.8-1,2	0,5 max	4,5-5,5	0.3-0,50	1,00-1,5	<0,02	<0,03
Cast Alloy Cr-Mo-V Steel Sample							
C	Si	Mn	Cr	V	Mo	S	P
0.41	0.9	0.21	4.5	0.3	1.02	0.01	0.01

3.2 Microstructure Investigations

The Scanning Electron Microscope (SEM) images of the SKD 6 steel showed in Figure 4. Picture of 4(a) is as received sample (imported steel) which shows some small spherical carbide known as Secondary Carbides (SCs). The secondary carbides are distributed evenly in the ferrite matrix with range of size 500 nm to 1 μ in the ferrite matrix. Figure 4(b) shows the microstructure of As-cast Cr-Mo-V steel. It has observed that the lath martensite was fully distributed in the alloy with the retained austenite (Meng et al., 2012; Qamar, 2015). Further, figure 4(c) is a cast alloy Cr-Mo-V steel after normalized. As can be seen in that figure, the microstructure is identical with the as-received sample. Nevertheless, the secondary carbides in normalizing sample tend to distributed in the grain boundary with the range of size 500 nm to 1 μ. Both SCs on sample are indicated as $M_{23}C_6$ carbides (Michaud et al., 2007).

Moreover, The SEM-EDS data (Figure 5) showed that there were Cr and Mo content in area 1 and area 3 that indicated $M_{23}C_6$ carbides.

Precipitation carbides on the grain boundaries due to high temperature known as sensitization. Heating the sample at the sensitization temperature will cause the C Atoms in the interstitial diffuse and tend toward the grain boundaries. However, Cr atoms are different. Cr atoms are hard to diffuse freely, even at high temperatures. Therefore, the C atoms at the grain boundaries will bind the atom Cr around it (Maulana and Sulistijono, 2015).



(a) (b) (c)

Figure 4: Microstructure of samples (a) As-received (b) As-cast (c) Normalized.

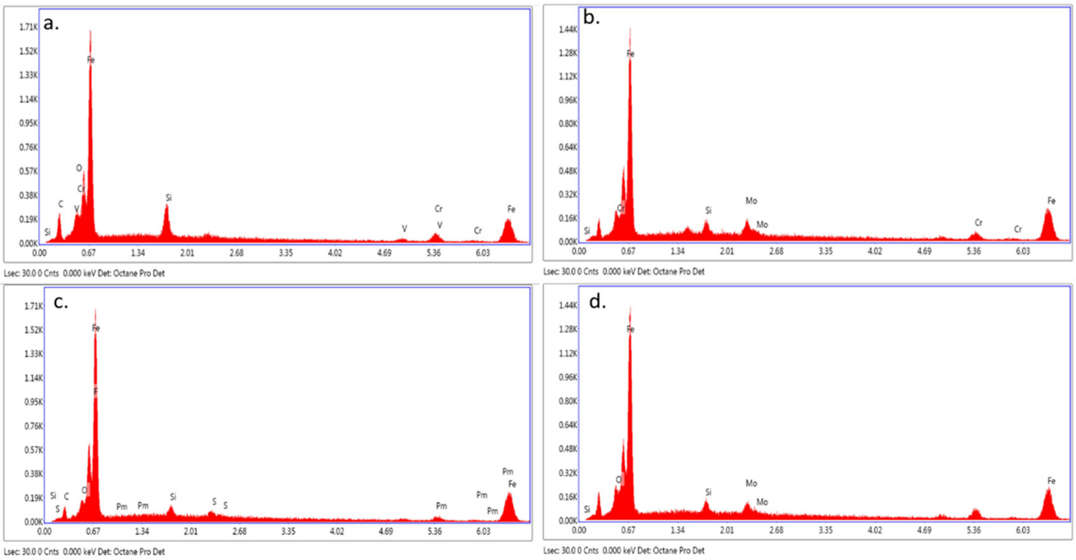


Figure 5: Graphics of Carbides SEM-EDS measurement (a) area 1 (b) area 2 (c) area 3 (d) area 4.

3.3 Hardness

Table 3 shows the hardness measurement by using Rockwell hardness tester type C. The as-received Cr-Mo-V alloy steel has higher hardness value 18.1 HRC than normalizing sample 13.6 HRC. Although the two samples had identical microstructures, the as-received samples had a higher SCs content, and the segregation was more even. This is what causes the hardness value of As-received sample to be higher, although not significant.

Table 3: Hardness test result.

Sample	Hardness (HRC)					Average (HRC)
	1	2	3	4	5	
As-received	18.3	18.1	17.7	17.9	18.3	18.1
Normalizing	13.4	13.7	13.3	13.8	13.7	13.6

4 CONCLUSIONS

The microstructural and hardness investigation on Imported Cr-Mo-V Steel and Cast Alloy Cr-M0-V Steel has been established. The observation showed that the microstructure of cast alloy Cr-M-V is identical to the as-cast product (imported) that has normalized. The microstructure showed that the normalized cast alloy has a ferrite matrix with spherical secondary carbide grain on the grain boundary. However, the hardness value of cast alloy Cr-M-V is slightly lower, 13.6 HRC, while the as-cast alloy is 18.1 HRC. The low hardness value may cause by the lower content of SCs in the casting sample and segregation from secondary carbide on the grain boundaries. With these results, the imported substitute material is suitable for use.

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