# TURNITIN Hot forgeability of SCr420

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# Hot forgeability of SCr420 low-alloy steel for piston rod application

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**Abstract.** Microstructure development and mechanical property of SCr420 low-alloy steel (equivalent to AISI 5120) obtained by the forging process have been investigated. The relationship between the forgeability and mean grain sizes were examined. The type of forging was carried out by die-forging at a temperature of around 1150 - 1190°C using a machine tonnage of 1600 tons capacity with 2 times forging variation. The high aspect ratio can be maintained through the steel forming applied for piston rod by the hot forging process. Vicker's hardness mechanical tests in initial and forged conditions were carried out at room temperature. The results demonstrate that the Vickers hardness of initial condition of 254.5 HV is much higher in comparison with the hot-forged material of 152.6 HV. The forged low-alloy steel processes the desired ferrite-pro eutectoid and pearlite microstructures, when followed by normalizing process, and deformation are achieved.

## 1. Introduction

Motorbike in Indonesia has become one of the preferable land transportation. This is advantaged by more practical and able to travel faster at a relatively low cost compared to other land transportations. A piston is one of the motorbike components which made by the forging process. Piston rod is a major component of the engine that serves to receive power obtained from combustion and forward it to the crankshaft. During the combustion process that occurs in the cylinder, the energy produced by the combustion gas is very high. If the piston and accessories are not able to withstand the explosive power of the combustion process, it can be sure that the piston rod can be damaged. The piston rod is also maximized to be able to withstand the force of the piston weight and combustion results in the cylinder. The piston rod which receives axial load must have its own flexibility and must be able to accept the load and the force of the piston [1]. Therefore, in the piston rod manufacturing that must be considered is the aspects of production technology, materials, violence, and others.

One of the important aspects of the piston rods manufacturing is the material. The material characteristics are used in producing piston rods must be heat-resistant, friction-resistant, and strong when resisting heavy workloads. The materials that commonly used in manufacturing piston rods are usually made by titanium due to lightweight and high strength to withstand loads [2]. In the case of small motors generally, piston rods are made by aluminum alloy due to handlebars lightweight.

Hot-forging in the manufacturing of piston rod components is the heat treatment process that one kind can be applied [3]. The microstructure and chemical composition of the steel can be developed by this process. In many applications, significant potential can be found in low-alloy steel [4]. Die casting has an appropriate forming method for SCr420 alloys, but insufficient use of casting results is due to unavoidable defects [4,5]. Better deformation on the SCr420 alloy can be produced through the hot-forging, one of the applications is on structural components, i.e. motorbike piston rods [6,7]. Hot-forging technology is a kind most efficient ways to produce a range of the dimension and design of finished parts which determined by factory standards so that it can also meet the demand for characterization [8,9].

However, one of the main factors that inhibit the wide application of SCr420 alloys is its poor to obtain better formability at room temperature and limited information on the process at elevated temperature treatment [3,10]. As for alloy systems, generally, the hardness increases with increasing alloy contents [11-16]. In order to develop new products to expand their use in SCr420 alloys, mechanical properties such as elastic, easily deformable, sufficient hardness, good machineability, and weldability must superior. Thus, SCr420 alloys with a composition of 0.18 to 0.23% C and 0.90 to 1.20% Cr alloys with a combination of superior properties, the conventional forging process was choosed and explored in this work.

## 2. Methods

The percentage of the chemical compositions in the SCr420 alloy used in this study are listed in Table 1. SCr420 alloy has a chemical composition where the chromium element has the largest percentage of 0.90 - 1.20 % classified as low chromium alloy steel [17]. A billet low-alloy steel was prepared by circular cutting machine Mada CMB 75 CNC type. Furthermore, SCr420 alloy was applied on a set of commercial continuous heating equipment at 1200 ± 30°C temperature for ± 20.75 sec vulnerable time and followed by rolling process at 1200 ± 10°C temperature for ± 5.78 sec vulnerable time. In addition, the forging machine was used to form the SCr420 alloy into a piston rod by die-forging type molds with 2 variations of forging time. Hot-forging was carried out by FP-1600 machine type at 1150 – 1190 °C temperatures for ± 17.55 sec vulnerable time with 1600 ton load, as shown in Figure 1.

**Table 1.** Chemical composition of SCr420 low-alloy steel based on JIS G4053 [17].

| | C (%) | Si (%) | Mn (%) | P (%) | S (%) | Ni (%) | Cr (%) | Mo |
|---|---|---|---|---|---|---|---|---|
| SCr420 | 0.18-0.23 | 0.15-0.35 | 0.60-0.90 | 0.03 max | 0.03 max | 0.25 max | 0.90-1.20 | bal. |

**Figure 1.** Several heat treatments processes of piston rod forming (a) rolling, (b) hot-forging and (c) normalizing

The heat treatment processes of piston rod forming were enhanced by trimming at 1035°C temperature for ± 8.87 sec time with a maximum tonnage of 160 ton. The trimming machine was used to cut the outer flash of SCr420 alloy. The final stage of the heat treatment processes is normalizing which used to remove the residual stress and transform the grain size. The normalizing process was done at 880°C temperature for 900 sec, followed by cooling in fanless air for 7200 sec time.

The microstructure evolution was characterized by a metallurgy type optical microscope with a constant magnification of 500× and 1000×. Parallel cutting with the thrust direction was done for all specimens by heat glitter annihilation and prepared with a size of 22 mm diameter × 230 mm length as defined in the standard. The epoxy resin was applied subjected to the mounting machine to obtain a flat image of microstructure evaluation and Vickers hardness test. A grit size range from 80 to 1000 mesh was applied to the surface mounting specimen then followed by a dip into the etching solution, in order to obtain the smooth surface and minimize the roughness. The intercept methods were chosen to determine the mean grain sizes as given in the literature works [18-24]. Vickers hardness was examined on the SCr420 alloy surface based on a certain compressive force of the inverted pyramid diamond indenter with a 136° peak angle. The constant load applied on the indenter is 2.94 N. Each object was tested at 5 different points with a distance of 100 mm. The Vickers hardness testing data were recorded automatically.

## 3. Results and Discussion

Figure 2 shows the raw material in a long condition with a size of 22 mm diameter × 230 mm length before used for making a piston rod. The microstructure change of hot forge ability was examined by a metallurgical microscope with a steady magnification of 500× and 1000×.

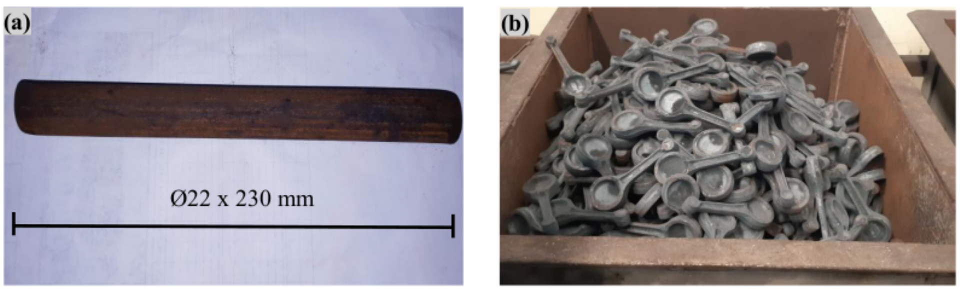


**Figure 2.** Specimens of (a) cutted SCr420 raw material size and (b) hot-forged piston rod.

The microstructure examination result of the SCr420 alloy shows that the initial condition without heat treatment specimen contains of ferrite and pearlite phase as shown in Figure 3 (a) and (b). After a hot-forging process with a temperature of 1150 - 1190°C for ± 17.55 sec, the microstructure of SCr420 alloy shows ferrite-pro eutectoid and pearlite phase, as shown in Figure 3 (c) and (d). The equiaxed grain microstructure of the initial raw SCr420 alloy with a mean grain size of 2.14 mm/grain, where the hot-forged SCr420 alloy mean grain size is 1 mm/grain. This grain refinement achieved due to the heat-treatment process. The grain diameter of SCr420 alloy is reduced by about 1.14 mm or decreased by 53 % of the raw material. Table 2 shows the result of grain refinement of raw and hot-forged of SCr420 alloy.

**Table 2.** Grain refinement analysis of initial raw material and hot-forged of SCr420 low-alloy steel.

| No | Initial raw | Hot-forged |
|---|---|---|
| 1 | Grain Size (mm/grain) | |
| | 2.14 | 1 |
| 2 | Shrinkage (%) | |
| | 100 | 53 |

The grain refinement analytical results indicated that the grain size of the SCr420 alloy hot-forged at 1150 – 1190 °C for ± 17.55 sec is reduced around 50 %. This phenomenon is also occurring in other researchers results during the hot-forging process [25-29]. The grain refinement of SCr420 alloy used in this research is not exactly similar size reduction with other references obtained [25-29], some deformation results show slightly higher and lower grain size after the hot-forging process. This difference results may be caused by the different beginning grain size, hot-forging, and pre- and post-heat treatment conditions, as well as the different materials.

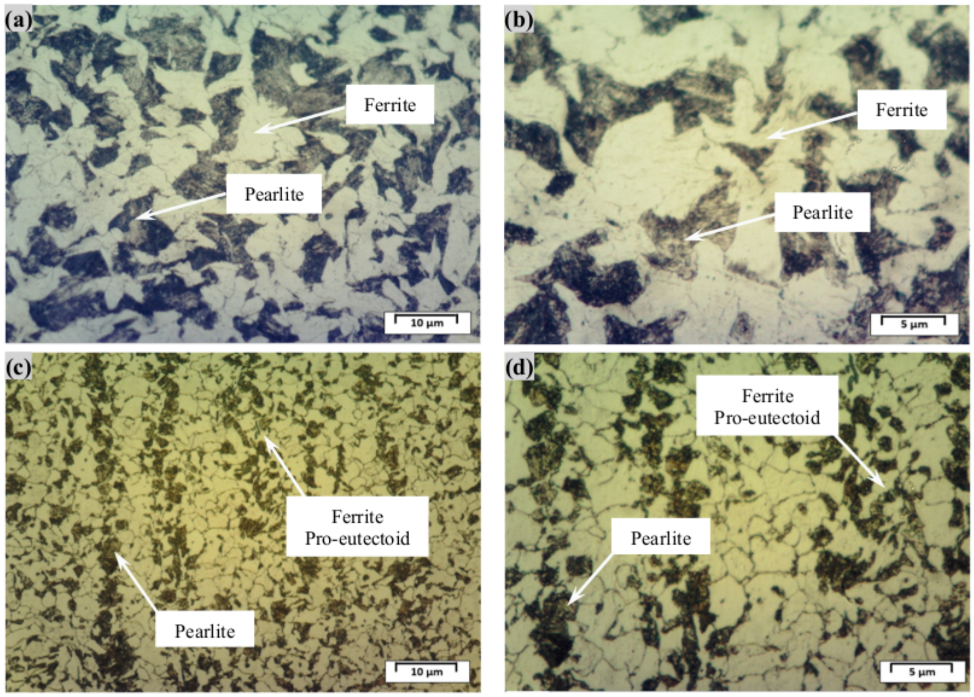


**Figure 3.** Microstructure of SCr420 alloy: (a and b) initial raw before heat treatment at (a) lower and (b) higher magnification, (c and d) after hot-forged at (c) lower and (d) higher magnification.

Figure 4 shows a graph of Vickers hardness test results by comparing raw materials of SCr420 alloy and specimens after the hot-forging process. The results obtained the hardness decreased, this possibility occurs because of the normalizing which is carried out after the hot-forging process. The purpose of the normalizing is to remove the stress, refine the grain, and reduce the hardness due to the long cooling time. In addition, it also can be caused by the characteristics of the raw material itself. There is a possibility that the microstructure of the raw material is deliberately made by coarse-grain diameter but has a high hardness before the heat treatment processes.

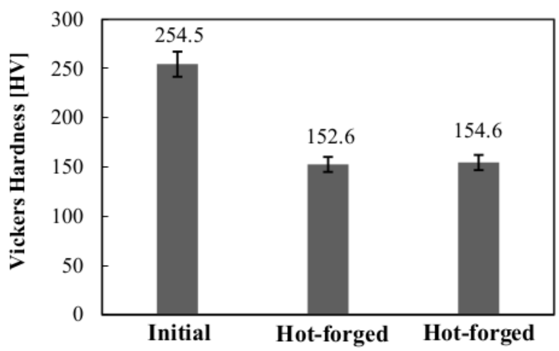


**Figure 4.** Average of Vickers hardness of initial raw material and hot-forged of SCr420 alloy

The results of the microstructure examination of SCr420 alloy show that there are differences in raw and hot-forged materials. Phase changes on SCr420 alloy are caused by the heat treatment process to austenite temperature or exceeding the eutectoid line, this phenomenon is relevant with the theoretical recrystallized microstructure in $Fe_3C$ phase diagram [30]. SCr420 alloy has a carbon content of 0.18 - 0.23% which is classified into hypo-eutectoid steel which means the carbon content is not more than 0.76%. In this research, the material will be heated first before the hot-forging process is carried out at 1200 ± 30 °C temperature which makes the material begin to develop its microstructure. The phase obtained at this temperature is austenite. Then at 850°C in the alpha and gamma regions which have a fairly high diffusion rate, alpha begins to form at the grain boundaries due to low carbon solubility limits. Then, at about 550 °C in the alpha region below the eutectoid line, the gamma phase infiltrated by carbon changes to $Fe_3C$ and begins to mix with the predominant ferrite phase, which blending the two phases will create a new phase, pearlite and ferrite phase that appears around the grain boundary surround by pearlite [30].

The phenomena of material undergo grain refinement can occur when the grain diameter decrease, the hardness will increase in line with the Hall and Petch equation. This is because by decreasing the diameter of the grain the boundary, the grain formation will be increased. A large grain boundary will inhibit dislocation movements which act as a barrier line so that the hardness of material increase. Based on the diagram of tensile strength, yield strength, hardness, impact energy with a carbon percentage, it appears that the lower the hardness, the yield strength, and tensile strength will also be lower [30]. However, there are differences in the elastic properties, if the hardness, yield strength, and tensile strength decrease, the strength of the load, the elasticity of the material will increase which will affect the machineability to be even better. The average hardness value obtained from hot-forged SCr420 alloy is considered to meet the specifications for further processing, where the material will have good machineability.

## 4. Conclusion

Based on the analytical results of experimental studies on SCr420 alloy has done, it can be concluded that the microstructure and its relationship to the average grain size are obtained, through the heat treatment experiments at elevated temperatures. The phase deformation occurred from ferrite-pearlite to ferrite-eutectoid-pearlite structure between Vickers hardness of 255 and 153 HV are accepted and completed with a forging temperature range between 1150 to 1190 °C. The desired defect-free microstructure is obtained from forged steel produced directly using the die-forged SCr420 alloy. Sufficient hardness properties and can realize savings of 53 % by weight and meet the demands for further and more precise engine capabilities compared to the similar piston rod components manufactured with structural steel alloys.

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