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# Influence of Vanadium on Fracture Splitting Property of Medium Carbon Steel

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**Abstract**: The fracture splitting property of medium carbon steel 37MnSiS microalloyed with V up to 0.45% was investigated by using simulated fracture splitting test, for the development of new crackable medium carbon steel to manufacture high performance connecting rod. Conventional high carbon steel C70S6 was used for comparison. The results show that the volume fraction of both ferrite and V-rich M(C,N) particles increases, and the pearlite interlamellar spacing decreases with increasing V content, which in turn results in gradual increase of strength and decrease of ductility and impact energy. The fracture splitting property of the tested steel could be improved significantly due to the increase of V content mainly through the precipitation hardening mechanism of fine M(C,N) precipitates. The fraction of brittle cleavage fracture in the crack initiation area increases noticeably with increasing V content and full brittle cleavage fracture surface could be obtained when V content was increased to 0.45%. It is concluded that medium carbon steel with V content higher than about 0.28% possesses not only comparable or even higher mechanical properties with those of conventional steel C70S6, but also excellent fracture splitting property, and therefore, is more suitable to fabricate high performance fracture splitting connecting rod.
**Key words**: microalloyed medium carbon steel; fracture splitting; vanadium; precipitation hardening; microstructure

Connecting rods are widely used in a variety of engines and their function is to transmit the thrust of the piston to the crankshaft, by translating the transverse motion to rotational motion. Owing to its importance, great attention has been paid to the performance and manufacturing technology of connecting rod. Fracture splitting technology, which was developed in the 1990s, is an important invention to manufacture high performance connecting rod[1]. Compared with conventional manufacturing process, this technique possesses significant merits such as cutting down the working procedures, reducing equipment and tools investment, as well as greatly improving product quality[1,2]. Accordingly, this technique has been investigated and applied widely to manufacture many types of connecting rods in recent years.

The material used for fabricating connecting rod is of great importance for it remarkably affects the process of fracture splitting. In general, the material used for automobile engine fracture splitting connecting rod requires high strength, low distortion on fracture splitting, appropriate brittleness and suitable machinability[1]. At present, high carbon steel C70S6 is one of the most widely used crackable forging steels for fracture splitting connecting rod[1-4].

The steel of C70S6 is based on pearlite steel SAE1070 and reveals cleavage fracture mode after fracture splitting. This fracture splitting property of C70S6 steel is similar to that of power forged material but the cost of the former is notably reduced[2]. The microstructure of C70S6 steel is mainly pearlite plus a small amount of discontinuous ferrite at prior austenite grain boundaries. However, there are some shortcomings for C70S6 steel compared with conventional microalloyed (MA) medium carbon steels such as 30MnVS and 38MnVS, which are now widely used to manufacture connecting rods, i. e., comparatively lower yield strength to tensile strength ratio and fatigue strength as well as poor machinability[5-10]. These shortcomings limit its further applica-

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tions to fabricate higher performance engines. Owing to the existence of fairly large fraction of rather soft phase of ferrite in traditional MA medium carbon steels, this would cause much plastic deformation during fracture splitting process. Accordingly, this kind of steels are not fit for the manufacturing of connecting rod using fracture splitting method[1,7-9]. Too much plastic deformation would cause poor rejoining in the fabrication of connecting rod. Thus, there have been more and more investigations to develop new high strength MA medium carbon steels which are suitable to manufacture high performance connecting rods by using fracture splitting method[1,7,9,11,12].

There are several methods to gain lower ductility and one effective and practical method is enhancing the hardness of ferrite. For example, decreasing Mn content and enhancing the contents of Si, P, V, Ti and N will help to gain lower ductility[7,9,12]. Among the commonly used elements, N, P and Si have most significant solid solution strengthening effect besides C. Therefore, the contents of these elements were often increased in the development of new crackable MA medium carbon steels[1,7,9,12]. Carbonitride of microalloying element of V (V(C,N)) has comparatively high solubility in austenite at convenient heating temperatures. Therefore, microalloying with V is widely used in medium carbon forging steels mainly for the purpose of precipitation hardening of fine V(C,N) precipitates in both proeutectoid ferrite and pearlitic ferrite. The usual addition of V is lower than 0.15% in traditional MA medium carbon steels and the effect of V on fracture splitting behavior has received limited attention in literature[5,6,8,10,13,14]. Previous studies have revealed that the fatigue properties of V-microalloyed medium carbon steels could be significantly improved mainly through properly controlled precipitation hardening of V(C,N)[15,16]. Thus, the purpose of the present study is to investigate the fracture splitting property of medium carbon steel 37MnSiS microalloyed with V up to 0.45%, to further understand the relationship between microstructure and manufacturing processes of MA steels, as well as the development of new MA medium carbon steel to manufacture of higher performance fracture splitting connecting rod. Conventional high carbon steel C70S6 to which fracture splitting process has been applied was selected for comparison.

## 1 Materials and Experimental Procedure

The chemical compositions of the tested steels with three different contents of V, which are named as MV1, MV2 and MV3, are given in Table 1. As mentioned above, compared with the conventional MA medium carbon steel 38MnVS, the P, Si, V and N contents of the tested 37MnSiVS steel were increased, whereas its Mn content was decreased[6,10]. The content of S was also increased to further enhance machinability, which is an important property concerning the considerable machining usually required after forging. High carbon crackable steel C70S6 was used for comparison. All the steels were melted in a laboratory vacuum-induction furnace and then cast into 110 kg tapered ingots. The as-cast ingots were reheated to 1200−1220 ℃ and held for at least 1 h, and then the ingots were press forged into rods and plates with finish forging temperature of about 850−900 ℃. All the forged rods and plates were finally cooled in still air. The diameter of the rods is 18 mm and the sizes of the plates are 25 mm in thickness and 70 mm in width.

**Table 1 Chemical compositions of the investigated steels** mass%

| Steel | C | Si | Mn | P | S | Cr | V | Al | N |
|---|---|---|---|---|---|---|---|---|---|
| MV1 | 0.37 | 0.80 | 1.05 | 0.033 | 0.086 | 0.17 | 0.15 | 0.021 | 0.018 |
| MV2 | 0.38 | 0.77 | 1.07 | 0.032 | 0.085 | 0.18 | 0.28 | 0.017 | 0.017 |
| MV3 | 0.38 | 0.74 | 1.03 | 0.033 | 0.088 | 0.18 | 0.45 | 0.024 | 0.020 |
| C70S6 | 0.65 | 0.26 | 0.61 | 0.012 | 0.086 | 0.18 | 0.03 | 0.018 | 0.017 |

Standard round bar tensile specimens ($l_0=5d_0$, $d_0=5$ mm) and Charpy impact specimens (10 mm×10 mm×55 mm, 2 mm V-notch) were cut longitudinally from the center of the $\phi$18 mm forged rods. Tensile test was carried out using a MTS 810 universal testing machine with constant cross-head speed of 1 mm/min at room temperature. Impact test was conducted with an impact testing machine at room temperature. Vickers hardness of the specimens was measured with a 5 N load and Vickers microhardness of both the ferrite portion and the pearlite portion were also measured respectively with a 0.05 N load. A minimum of 10 hardness measurements was made on each sample.

Simulated fracture splitting test was used to evalu-