为何含碳量高的钢材容易断裂？ Why high-carbon steel is prone to fracture?

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含碳量高的棒材发生过很多次断裂，如45#钢做的轴，使用不太长的时间就发生断裂。从断裂后部件上取样，进行金相分析，往往找不到产生的原因，即算牵强附会找到了一些原因，也不是实际的原因。

High-carbon steel bars have experienced many fractures, such as shafts made of 45# steel, which have broken after a relatively short period of use. When samples are taken from the fractured parts for metallographic analysis, it is often difficult to find the actual cause of the fracture, even if some reasons are found by force-fitting, they are not the actual causes.

为了确保更高的强度，还必须在钢中添加碳，随之就会析出铁碳化物。从电化学的观点来看，铁碳化物发挥了阴极作用，加快了基体周边的阳极溶解反应。在显微组织内的铁碳化物体积分数的增大还归因于碳化物的低氢超电压特性。

In order to ensure higher strength, it is necessary to add carbon to the steel, which will result in the precipitation of iron carbides. From an electrochemical perspective, iron carbides play a cathodic role, accelerating the anodic dissolution reaction around the matrix. The increase in the volume fraction of iron carbides within the microstructure is also attributed to the low hydrogen overvoltage characteristics of the carbides.

钢材表面易于产生并吸附氢，氢原子向钢材内部渗入的同时，氢的体积分数就可能会增加，最终使得材料的抗氢脆性能显著降低。

The surface of steel is prone to produce and adsorb hydrogen. As hydrogen atoms penetrate into the interior of the steel, the volume fraction of hydrogen may increase, ultimately significantly reducing the material's resistance to hydrogen embrittlement.

高强钢材耐腐蚀性和抗氢脆性的显著降低不仅有害于钢材的性能，还会极大地限制钢材的应用。

The significant reduction in the corrosion resistance and resistance to hydrogen embrittlement of high-strength steel is not only harmful to the performance of the steel but also greatly limits the application of the steel.

如汽车用钢暴露于氯化物等各种腐蚀环境中，在应力作用下，可能出现的应力腐蚀开裂（SCC）现象就会对车身的安全性造成严重的威胁。

If automotive steel is exposed to corrosive environments such as chlorides, stress corrosion cracking (SCC) may occur under stress, posing a serious threat to the safety of the body.

碳含量越高，氢扩散系数减小，氢溶解度增大。学者Chan曾经提出，析出物（作为氢原子的陷阱位置）、电位、空孔等各种晶格缺陷与碳含量成正比，碳含量增大，就会抑制氢扩散，因此氢扩散系数也较低。

The higher the carbon content, the lower the hydrogen diffusion coefficient, and the higher the hydrogen solubility. Scholar Chan has proposed that precipitates (as trap positions for hydrogen atoms), potential, voids, and various lattice defects are proportional to the carbon content. As the carbon content increases, hydrogen diffusion is suppressed, resulting in a lower hydrogen diffusion coefficient.

由于碳含量与氢溶解度成正比关系，作为氢原子陷阱的碳化物，体积分数越大，钢材内部的氢扩散系数越小，氢溶解度增大，氢溶解度也包含了有关扩散性氢的信息，因而氢脆敏感性最高。随着碳含量的增加，氢原子的扩散系数减小，表面氢浓度增大，这是因为钢材表面的氢超电压下降所致。

Due to the proportional relationship between carbon content and hydrogen solubility, as the volume fraction of carbides, which act as traps for hydrogen atoms, increases, the hydrogen diffusion coefficient within the steel decreases, and the hydrogen solubility increases. The hydrogen solubility also includes information about the diffusivity of hydrogen, making the hydrogen embrittlement sensitivity the highest. With the increase in carbon content, the diffusion coefficient of hydrogen atoms decreases, and the surface hydrogen concentration increases, which is due to the decrease in the hydrogen overvoltage on the steel surface.

从动电压极化试验结果来看，试样的碳含量越高，酸性环境中就易于发生阴极还原反应（氢生成反应）以及阳极溶解反应。与具有低氢超电压的周边基体进行比较，碳化物发挥了阴极的作用，其体积分数增大。

From the results of the dynamic potential polarization test, it was found that the higher the carbon content of the sample, the more likely it is to undergo cathodic reduction reactions (hydrogen generation reactions) and anodic dissolution reactions in an acidic environment. Compared with the surrounding matrix with a low hydrogen overvoltage, the carbides act as cathodes, and their volume fraction increases.

根据电化学氢渗透试验结果，试样内的碳含量和碳化物的体积分数越大，氢原子的扩散系数就越小，溶解度增大。随着碳含量的增加，抗氢脆性也会降低。

According to the results of electrochemical hydrogen permeation tests, the higher the carbon content and the volume fraction of carbides in the sample, the smaller the diffusion coefficient of hydrogen atoms, and the greater the solubility. With the increase in carbon content, the resistance to hydrogen embrittlement also decreases.

慢应变速率拉伸试验证实，碳含量越大，抗应力腐蚀开裂性能也会降低。与碳化物的体积分数成正比，随着氢还原反应及向试样内部渗透的氢注入量增加，就会发生阳极溶解反应，也会加快形成滑移带。

The slow strain rate tensile test confirms that the higher the carbon content, the lower the resistance to stress corrosion cracking. It is proportional to the volume fraction of carbides, and with the increase in hydrogen reduction reactions and the amount of hydrogen injected into the sample, anodic dissolution reactions occur, and the formation of slip bands is also accelerated.

碳含量的增大，钢材内部就会析出碳化物，在电化学腐蚀反应的作用下，氢脆可能性就会增大，为了确保钢具备优秀的耐腐蚀性和抗氢脆性，对碳化物的析出和体积分数的控制进行是有效的控制方法。

With the increase in carbon content, carbides will precipitate within the steel, and under the action of electrochemical corrosion reactions, the possibility of hydrogen embrittlement increases. To ensure that the steel has excellent corrosion resistance and resistance to hydrogen embrittlement, controlling the precipitation and volume fraction of carbides is an effective control method.

钢材在汽车零配件上的应用受到一些限制，也要归因于其抗氢脆性能的明显下降，而氢脆是由水溶液腐蚀产生的。事实上，这种氢脆敏感性是与碳含量密切相关的，在低氢超电压条件下析出铁碳化物（Fe2.4C / Fe3C）。

The application of steel in automotive components is limited to some extent, also due to the significant decrease in its resistance to hydrogen embrittlement, while hydrogen embrittlement is caused by aqueous corrosion. In fact, this hydrogen embrittlement sensitivity is closely related to the carbon content, and iron carbides (Fe2.4C / Fe3C) precipitate under low hydrogen super voltage conditions.

一般针对应力腐蚀开裂现象或氢脆现象导致的表面局部腐蚀反应，通过热处理除去残余应力，增大氢陷阱效率等方面开展。要想开发兼具优秀耐腐蚀性和抗氢脆性的超高强汽车用钢，也自然并非易事。

Generally, for surface local corrosion reactions caused by stress corrosion cracking or hydrogen embrittlement, efforts are made to remove residual stress through heat treatment and increase the efficiency of hydrogen traps. Naturally, it is not an easy task to develop ultra-high-strength automotive steel with excellent corrosion resistance and anti-hydrogen embrittlement properties.

随着碳含量的增大，氢还原速率增大，而氢扩散速率显著降低。使用中碳或高碳钢做零部件或传动轴等，技术关键就是对显微组织中的碳化物组分进行有效控制。

With the increase in carbon content, the rate of hydrogen reduction increases, while the diffusion rate of hydrogen significantly decreases. The technical key for using medium or high carbon steel for parts or drive shafts is to effectively control the composition of carbides in the microstructure.