Fracture behavior of high strength steel in tension after fire exposure

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Summary

High-strength steels are utilized for high-rise and large space structures in tension thanks to their high yield strength. However, they are subject to deterioration in their material properties, such as strength, elastic modulus and ductility if they operate in high temperature. More specifcally, if they are exposed to fire, their fracture behavior needs to studied carefully. There are two factors deciding the fracture behavior of high-strength steels after fire exposure: exposure temperature magnitude and cooling conditions.

First, stress triaxiality has an impact of fracture behavior of high-strength steels. Stress triaxiality is significantly great when the steels are in tension, increasing the strength by 50% yet decreasing ductility by 75%. In event of fire, high stress triaxiality combined with martensite formation greatly reduces the structure's ductility and plastic strain at fracture initiation. Consequently, the post-fire fracture behavior of high-strength steel tension members should be given adequate analysis.

The types of steels also have different properties when exposed to fire. For example, in mild steels, their strength, modulus and ductility do not alter noticeably even after fire exposure, On the other hand, high-strength steel's properties are much more subject to great changes in high temperature more than 400-600°C . For example, RQT-S690 steel displays strength reduction and ductility increase, while the yield strength of steels G500 and G550 can recover up to 80%.

There are often two cooling methods in considerations: air cooling and water cooling. The changes in properties above are in the case of natural air cooling. Water cooling method will yield different results in high-strength steels' properties after fire exposure. In mild steels, water cooling reduces their ductility due to martensite formation. For Q460 and Q690 steel at 700°C, air cooling method increases ductility while water cooling decrease ductility. Overall, cooling method has a varying effect on the ductility of different types of steels.

The fracture mechanics of high-strength steels can be studied from the knowledge of properties change during fire exposure and after being cooled. In fracture analysis, damage evolution law defines how the material degrades after one or more damage initiation criteria are met, More specifically, it describes damage growth in materials during necking and fracture. The law is found to be related to stress state, ductility and fracture resistance. Damage evolution after high temperature exposure and cooling down depends on various factors such as chemical composition, grain size, plastic displacement and toughness index.

According to the damage evolution law, the larger toughness index index, the higher the steel's resistance to fracture. As soon as necking starts to take place, cracks are initiated and damage starts to propagate the steel. The situation becomes particularly dangerous if the damage index reached 1.0, when the steels are completely fractured. Fracture and plastic deformation are less likely to occur if the steels are more resistant to damage initialization.

Not all steels display the same damage evolution when exposed to fire. The differences between models of high-strength steels can be traced from different material properties and also depend on the sample tested steels, the magnitude of the exposed temperature and the cooling method. Therefore, to understand the fracture behavior of these steels, further metallurgical analyses are required to obtain more details about the steel, such as its compositions and grain size

Literature

Wen-Yu Cai, Jian Jiang, Yan-Bo Wang, Guo-Qiang Li, Analysis of fracture behavior of high-strength steels in tension after fire exposure, Engineering Structures, Volume 231, 2021, 111750, ISSN 0141-0296

Additive manufacturing for steels

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Summary

Nowadays steels are indispensable parts of many manufactures, products and buildings. That is why steel production costs need to be minimized as much as possible while the steel's quality must be consistently improving. In the light of such goal, additive manufacturing (AM) proves to be a good candidate for steel production technique. Additive manufacturing is essentially a form of 3D printing that is capable of producing solid parts from 3D image data via layer processing. There are two different typess of AM: powder bed technique (PB) and flow-based technique. We willinvestigate how these two techniques can create 3D printing of high-quality steels.

Powder bed technique has two distinct processes: electron beam melting (EBM) and selective laser melting (SLM). The process works as follows: the roller keeps pushing powder from the elevated powder delivery system into the powder bed. Then the scanner receives input from 3D image data and reflects the laser shot from the laser machine into the powder. The powder is melted and left to solidify into high-grade steel. The process continues until the steel component is finished, creating a 3D model. The PB method has an advantage of delivering high density steels with good mechanical properties and smooth surface. There is one drawback of this technique which is that it is limited to produce small scale steels due to the limited capacity of the technology and the laser beam.

Flow-based technique involves many technology, which are normally consisting of laser-engineered net shaping (LENS), direct metal deposition (DMD) and direct metal laser sintering (DMLS). In contrast to the continuous flow of powder, the low-based method applies melting on discrete number of powder layers. In the process, the beam guidance system will control the laser into melting each layers of powders. The powder is poured into the deposit via the deposition head from the power supply. As each layer's melting and solidifying finishes, new layers of powder are stacks on each other until a steel product is finished. Despite lacking precise dimensioning and smooth surface product compared to powderbed technique, flow-based technique is capable of building large scale products thanks to its high deposition rate and volume.

After additive manufacturing, steel products' microstructure and mechanical properties need to be examined. The steel's properties mainly depend on the manufacturing parameters such as laser power and scanning speed. Repeat heating and cooling creates a thermal cycle, which induces the steel to have columnar grains. The non-equiaxed grains thus makes the steel become anisotropic in tensile strength and possess crystallographic texture. Different levels of cooling and heating changes the mechanical properties as well. For example, during rapid cooling, the main form of solidified phases are delta ferrite and martensite. Thermal cycle history therefore can control steel's properties by adjusting the manfacturing parameters

There are several challenges in the AM process. For example, stacking layers of powders may have a thermal gradient that leads to residual stress. Also, despite its high accuracy, the electron beam used for melting the powder needs to operate in a vacuum space.

Naturally, AM technology has advantages over traditional steel production. Thanks to the precision of computers, the laser beam can deliver much more accuracy. First, for steel products that need complicated patterned geometry, AM production proves to be effective in creating the desired product. Secondly, there are small details in the product, which can only be fabricated with the precision of laser beam melting.

In conclusion, additive manufacturing is an efficient and cost-effective way of steel production

Literature

Additive manufacturing for steels: a review, A Zadi-Maad *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.*