Study on Bending Beam Delayed Cracking of Ultra High-strength DP Steel for Automotive Use

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Abstract: Automobile lightweight project can effectively reduce energy consumption and exhaust emission, but it will reduce automobile safety. Therefore, using a large number of high-strength or ultra-high-strength steels in automobiles is an effective way to give consideration to both lightweight and safety. Delayed cracking is a symptom-free cracking phenomenon, which is extremely destructive. It is necessary to evaluate the delayed cracking performance of ultra-high-strength steel before it is used. In this paper, the delayed cracking properties of three ultra-high strength dual-phase steels DP780, DP980 and DP1180 for automobile are studied by bending beam delayed cracking test. The experimental results show that the delayed cracking resistance of DP780, DP980 and DP1180 steel becomes worse in turn, and DP1180 steel has the worst delayed cracking resistance. In addition, the content and morphology of martensite will affect the delayed cracking performance. The morphology of martensite in the tested steel is lathy, and the higher the martensite content, the worse the delayed cracking resistance of the steel.

1.introduction

With the continuous development of society, people have higher and higher requirements for environmental protection. In recent years, with the rapid development of automobile industry, the air...
pollution caused by automobile exhaust is becoming more and more serious, so the requirements for energy saving and emission reduction of automobiles are getting higher and higher. Automobile lightweight project can effectively reduce energy consumption and exhaust emission, but it will reduce automobile safety. Therefore, using a large number of high-strength or ultra-high-strength steels in automobiles is an effective way to give consideration to both lightweight and safety. For example, in Honda's third generation fit body structure, the utilization rate of steel with tensile strength exceeding 1000MPa reaches 10%, among which the utilization rate of steel with 1500MPa grade reaches 2%. However, with the improvement of steel strength, especially when its tensile strength exceeds 1200MPa, delayed cracking is easy to occur \cite{1-3}. Delayed cracking is a phenomenon of sudden brittle failure of materials under static stress after a certain time, and it is an environmental embrittlement caused by the interaction of materials, environment and stress \cite{4-6}. Delayed cracking is a symptom-free cracking phenomenon, which is extremely destructive, so it is necessary to evaluate the delayed cracking performance of ultra-high strength steel before it is used.

In this paper, the delayed cracking properties of DP780, DP980 and DP1180 Dual Phase steels for ultra-high strength vehicles are studied by bending beam delayed cracking test. The microstructure of the tested steels and the fracture morphology of the samples after bending beam test are observed by scanning electron microscope and the relationship among delayed cracking properties, strength and microstructure of the tested steels is divided, which provides a reference for the evaluation of delayed cracking properties of ultra-high strength DP steels for vehicles.

2. test materials and methods
The grades of three kinds of ultra-high strength DP steels for vehicles are DP780, DP980 and DP1180 respectively. The specific chemical composition of the test steel is shown in Table 1.

| material trademark | C     | Mn     | Si     | Al    | Nb+V+Ti |
|-------------------|-------|--------|--------|-------|---------|
| DP780             | 0.10  | 2.10   | 0.18   | 0.054 | <0.050  |
| DP980             | 0.15  | 1.52   | 0.57   | 0.048 | <0.040  |
| DP1180            | 0.12  | 2.43   | 0.28   | 0.035 | <0.055  |

Sample the side of the test steel along the rolling direction, inlay, grind and polish the sample along the rolling direction, etch and dry it with 4% nitric alcohol, and observe the microstructure under scanning electron microscope.

In the delayed cracking test of curved beams, 5%HCl aqueous solution was used as corrosion medium to simulate the test environment, and the ambient temperature was room temperature. The prestress of the test steel plate was added to three stress states of 1.0GPa, 1.5GPa and 2.0GPa respectively. There are 15 samples of each steel under each prestress, and the sample size is 2×20×150(mm), as shown in Figure 1. The sample after loading and fixing is shown in Figure 2. Finally, the sample was put into 5%HCl aqueous solution for testing. During the experiment, pay attention to close observation within 2 hours, observe once every 10 minutes within 2-4 hours, and finally extend the observation time interval gradually. The fracture time of the sample is taken as the time when the sample is found to be completely broken during observation.

![Fig.1 The sketch of sample](image-url)
3. test results and analysis

3.1. microstructure
The microstructure of ultra-high strength DP steel for automobile is shown in fig.3, the main microstructure of the three test steels is martensite (M) + ferrite (F). It can be seen from fig.3a that the microstructure of DP780 steel is mainly martensite (M) + ferrite (F), in which the gray flat area is ferrite (F), and the convex gravel-like structure distributed on the flat ferrite structure is martensite (M). Martensite in DP980 steel is distributed on ferrite in island shape, as shown in fig.2c. The microstructure of DP1180 steel (as shown in fig.3b) is mainly composed of lath martensite matrix and a small amount of grain boundary ferrite, in which lath region is martensite structure and concave polygonal region is ferrite structure. It can also be found from fig.3 that with the increase of strength grade of the test steel, the martensite content in the microstructure gradually increases, while the ferrite content gradually decreases. The martensite content in DP1180 steel is the highest and ferrite content is the lowest. In addition, the morphology of martensite in the test steel changed from crushed stone (DP780 steel) to island (DP980 steel) and finally to strip (DP1180 steel).
3.2 Test results

Table 2 shows the average cracking time of three kinds of ultra-high strength DP steels for vehicles after bending beam delayed cracking test in 5%HCl solution for 1000 hours. It can be seen from table 2 that all samples of DP780 have no fracture phenomenon and no crack under three pre-stresses of 1.0GPa, 1.5GPa and 2.0GPa. Under three kinds of prestress conditions, DP980 has few fracture specimens, only two specimens have fracture under 1.0GPa and 1.5GPa prestress, and five specimens have fracture under 2.0GPa prestress. At first, DP1180 steel cracked, and all specimens with prestress of 2.0GPa broke. However, when the prestress is 2.0GPa, the fracture time is quite different, the shortest is about 10 hours, and the longest is over 500 hours. Under the prestress of 1.5GPa, the samples of DP1180 steel did not break completely, the minimum time was more than 10 hours, and the maximum time was more than 500 hours, the big gap may be caused by different materials of DP1180 samples in the same batch. There are only three samples of DP1180 fracture under the prestress of 1.0GPa, and the average fracture time is over 333 hours, and the maximum fracture time is over 400 hours. It can be found from table 2 that among the three DP steels, DP780 steel has the best delayed cracking resistance, followed by DP980 steel, while DP1180 steel has the worst delayed cracking resistance.

| Prestressing Force | DP780     | DP980     | DP1180    |
|--------------------|-----------|-----------|-----------|
| 1.0GPa             | Uncracked | 460.3(2 cracks) | 333(2 cracks) |
| 1.5GPa             | Uncracked | 16.3(2 cracks)  | 167.36    |
| 2.0GPa             | Uncracked | 16.3(5 cracks)  | 82.4      |

In addition, it can be found that DP steels with three strength grades break within 48 hours (about 8 hours), and the fracture is flat, which belongs to brittle fracture and is basically characterized by delayed fracture, as shown in Figure 4. Fig.4 shows the fracture morphology of DP1180 steel after bending beam test under 2.0GPa prestress, from fig.4a, it can be found that when the sample is broken, no obvious corrosion phenomenon is found, no pitting pits appear, the fracture is smooth, no obvious plastic deformation is found, and it is brittle fracture. Fig.4b shows the microscopic fracture under scanning electron microscope, from which it can be found that the fracture is mainly cleavage fracture, and local intergranular fracture is brittle fracture. Corrosion products are rarely found in fracture, which should belong to hydrogen-induced delayed cracking fracture.
Fig. 4 Fracture morphology of DP1180 steel after 2.0 GPa prestressed bending beam test
(a) macroscopic image; (b) SEM image

However, when the fracture time is much longer than 48 hours (about 403 hours), there are a large number of corrosion pits, mainly corrosion fractures, and few flat fractures, as shown in Figure 5. Fig. 5 shows the fracture morphology of DP1180 steel after bending beam test under 1.0 GPa prestress, from Fig. 5a, it can be found that when the sample is broken, a large number of corrosion pits appear, and corrosion fracture is dominant, with few flat fracture. Fig. 5b shows the microscopic fracture under scanning electron microscope, from the figure, it can be found that there are a lot of corrosion products in the fracture, so that the fracture mechanism can not be seen clearly, from the low-power SEM photograph, it is probably cleavage fracture, which should belong to stress corrosion cracking fracture.

Fig. 5 Fracture morphology of DP1180 steel after 1.0 GPa prestressed bending beam test
(a) macroscopic image; (b) SEM image

Fig. 6 shows the beam bending test results of DP980 and DP1180 steel in 5%HCl solution. It can be seen from the figure that the fracture time of DP1180 steel is much shorter than that of DP980 steel, and most samples (more than 10) of DP980 steel will not break within 1000 hours. In addition, it can be found that the fracture time of DP980 steel and DP1180 steel is concentrated at both ends, that is, short-time fracture, which is basically within 48 hours, and long-time fracture, which is close to 1000 hours, even does not appear after the test. In DP1180 steel, the fracture time of individual samples (3 samples) is shorter, and the average fracture time of these samples is more than 350 hours. The fracture morphology of these two kinds of fractured samples with fracture time is also obviously different. Short-time fracture (within 48 hours), with flat fracture, belongs to brittle fracture, and is basically characterized by delayed fracture. Long-term fracture (fracture time is much longer than 48 hours) shows a large number of corrosion pits, mainly corrosion fracture, and few flat fracture.
It is generally believed that the existence of martensite will seriously reduce the delayed cracking resistance of steel\textsuperscript{[7]}, so the more martensite, the worse the delayed cracking resistance. It can also be found from fig.3 that with the increase of strength grade of the test steel, the martensite content in the microstructure gradually increases, while the ferrite content gradually decreases. The martensite content in DP1180 steel is the highest and ferrite content is the lowest. In addition, the martensite morphology of three DP steels is also different. The martensite morphology of DP780 steel is crushed stone, which is on ferrite matrix respectively. In DP780 steel, martensite is used as strengthening phase, ferrite is used as main bearing phase, which bears stress. The morphology of martensite in DP980 steel is island, and the area of single martensite increases on ferrite matrix. In DP980 steel, martensite and ferrite are the main bearing phases, which bear the stress together. The morphology of martensite in DP980 steel is island, and the area of single martensite increases on ferrite matrix. In DP980 steel, martensite and ferrite are the main bearing phases, which bear the stress together. The morphology of martensite in DP1180 steel is lath, and as a matrix, a small amount of ferrite is distributed at the grain boundary of martensite matrix. In DP980 steel, martensite is used as bearing stress and ferrite toughening phase. Martensite in DP1180 steel is lath and serve s as the main bearing phase, and the existence of martensite will seriously reduce the delayed cracking resistance of steel. Therefore, among the three DP steels, DP780 steel has the best resistance to delayed cracking, followed by DP980 steel, while DP1180 steel has the worst resistance to delayed cracking.

4 Conclusion
(1) The bending beam test results show that the delayed cracking resistance of DP780, DP980 and DP1180 steel becomes worse in turn, and the delayed cracking resistance of DP1180 steel is the worst.
(2) The microstructure has an important influence on the delayed cracking performance of the test steel, and the content and morphology of martensite will affect the delayed cracking performance. The morphology of martensite in the tested steel is lathy, and the higher the martensite content, the worse the delayed cracking resistance of the steel.

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