Propagation and Evolution of Cracks in GFRP under Repeated Impacts

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Abstract

In order to study the law of crack propagation in GFRP under repeated impact, the low speed impact tests were carried out on glass fiber with a thickness of 1mm and an area of 20cm*20cm produced by a layer of alkali glass fiber and E44 epoxy resin, and the image of cracks formed on the surface of GFRP after shock was collected by electron microscope, and the length and width were measured. Experimental results show that the effect was obviously caused by the impact on the crack propagation, and a considerable fitting formula was obtained to explain this phenomenon. But the impact work has the critical value which made the initial crack appear. The depth of the crack under the different times impact was studied to confirm the development model of the crack: the crack length will change suddenly under the a cumulative critical impact work. Combined with the impact dynamic theory, an obvious result will be obtained that the effect of the impact velocity has greater saliency under the same impact work.

Keywords

GFRP, Low velocity impact ,electron microscope,crack.

1. Introduction

Glass fiber reinforced plastic (GFRP), also called glass fiber reinforced plastics, refers to plastic products made of glass fiber reinforced thermosetting resin. As a new type of building material, GFRP has the advantages of good corrosion resistance, light weight, high strength, good insulation and good thermal insulation performance. Therefore, in recent years, GFRP materials in building construction and bridge engineering and other architectural design have been more and more widely used. The research of GFRP is very early , but there is little research on the properties of GFRP under repeated impact, and the research on the material properties under the impact of single impact is more.

In order to investigate the characteristics and application methods of GFRP materials, a great deal of work has been carried out by scholars , and fruitful results have been achieved. Yang Yiqian et al. [1] studied the dynamic mechanical properties of GFRP by impact compression test. Li Xiangyu et al. [2] studied the deformation and failure of GFRP by loading different time length loads. Osman, Hag-Elsafi et al. [3] studied the dynamic characteristics of Bentley Creek Bridge with GFRP as the deck. It was concluded that the basic frequency of the main flexural structure increased by 45% when the concrete was replaced with a GRP deck. Sourabha S. Havaldar [4] studied the effect of cellular size on GFRP honeycomb sandwich plate frequency, and loading test was carried out on the specimens with two different boundary conditions (only on one side of the rectangular rectangle clamping; edge clamping). Although the study of GFRP is relatively early, there are few studies on the evolution of cracks in GFRP under the impact of multiple shocks. However, in most cases, people can not guarantee that GFRP must only be subjected to a single impact, and the GFRP might not be broken by the impact. In many cases, GFRP can be broken under the next impact, so it is necessary to study the evolution law of GFRP cracks under the repeated impact.

2. Materials

2.1 Experimental device

PV Impact tester made by Lixin Instrument in Dongguan Guangdong, and the series number is LX-5621.The device is free to fall, and the highest is 2m. Experimental device was showed in figure 1:

Fig.1 Experiment device

2.2 Experimental specimen

The type of the specimens is the same as the 3240 epoxy plate.The specimens are 20cmX20cm square thin plate with yellow primary colors,the average thickness is controlled of 1mm;3240 is the national brand, corresponding to the EPGC201 type in IEC893-3-2.3240 epoxy boards are made of medium alkali glass fiber and epoxy resin E44 by drying and hot pressing.The specimen is commissioned to be processed by third parties, and the preparation process is strictly carried out in accordance with GB/T1303.1-1998[5].

2.3 Experiment program

The weight drop and drop height are set as the variables in experiment. Control variable method was adopted to change the weight and the height of the drop.The GFRP was impacted 20 times, and the experiment would not be stopped until the normal test can not be continued by the specimen. After each impact, the cracks were taken with an electronic microscope, and the length and width of the crack and were recorded. The drop height of the heavy ball was set on the ratio between the four heavy balls chosen, and the highest height was 2 meters, then another three kinds of height were obtained by the ratio.The drop balls' mass and height were showed as Table 1.

Table 1. Experimental design

Number	1	2	3	4
Mass / Kg	0.11	0.225	0.535	1
Height / m	0.22	0.45	1.07	2

3. Experiment result

Tests are carried out in accordance with the above scheme, the development of crack under different impact work is shown in Figure 2.

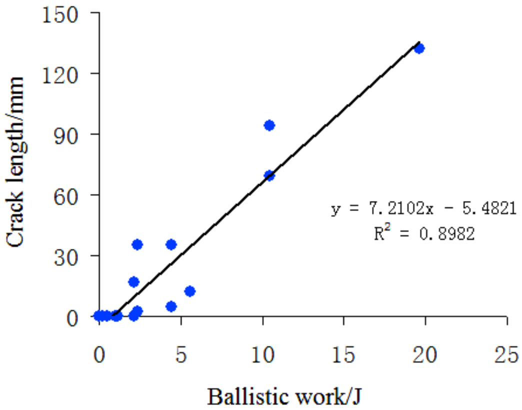
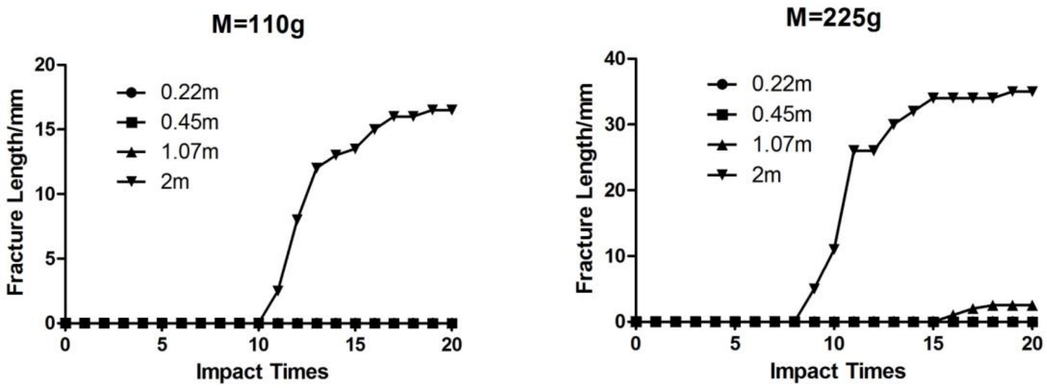
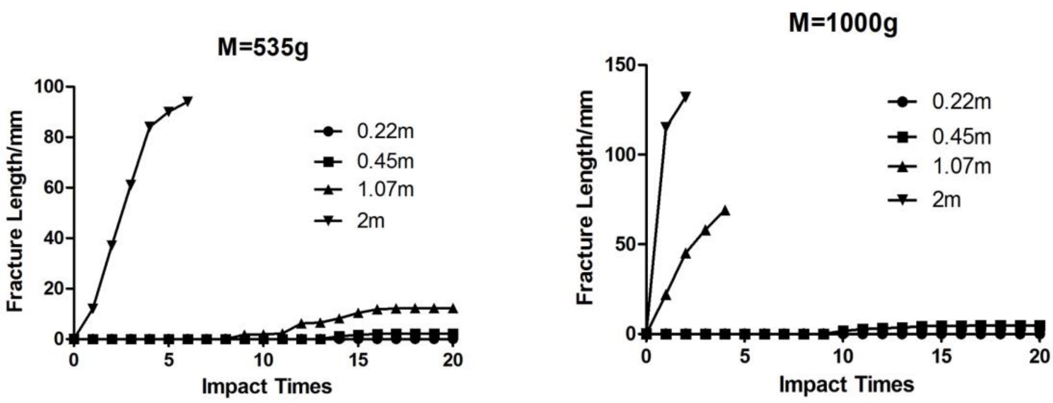


Fig. 2 Diagram of the development of crack under different impact work

According to the Figure 2,there is an obvious linear relationship between the falling ball impact work and the crack length of the GFRP. A lager correlation coefficient square value(R2=0.898)showed a good linear relationship between the two factors. The linear function doesn't pass the origin, it is because that the impact work is so small that all of the energy was absorbed by the fiberglass cloth.so the cracks could not be caused by the impact work. Under the same impact work, the crack length could not be caused by it was not consistent. An reasonable speculation is that when the impact is consistent, the effect of the impact on the GFRP by under different mass and impact velocity is not consistent.According to the experiment scheme, the trend figure of cracks after 20 impact of different mass falling balls is shown in Fig. 3.



(a) 110g (b) 225g

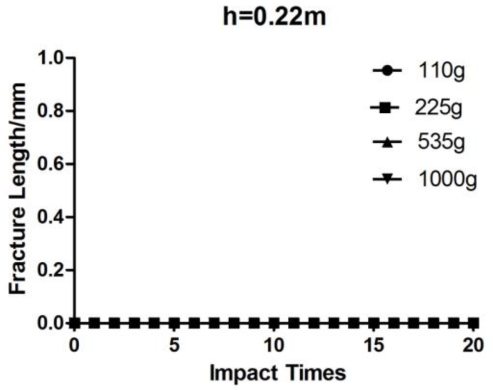


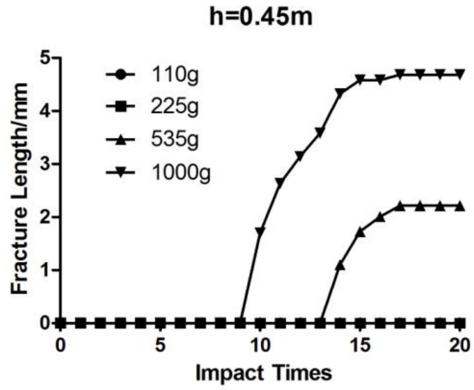
(c) 535g (d) 1000g

Figure 3. The crack accumulation of different mass falling balls under repeated impact

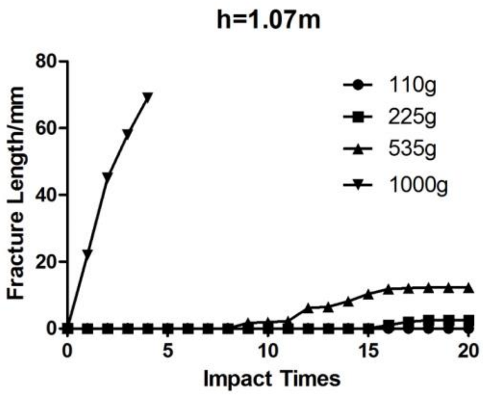
In the Figure 3-a,when the falling ball mass is 110g,only when the falling height is 2m, the crack would be caused by the ball in the GFRP and the crack would occur at the tenth impact.In the Figure 3-b,when the falling ball mass is 225g,the crack would be caused by it when it fell from the height of 1.07m and 2m,and the changing speed of the cracks increased with the falling height increasing.In the Figure 3-c,when the mass of the falling ball was 535g,accept the case of height of 0.22m,the cracks of the GFRP could be caused by the impact work produced by the falling balls falling from all of another height,besides,the changing speed of the cracks increased with the falling height increasing. In the Figure 3-d,when the mass of the falling ball was 1000g,accept the case of height of 0.22m,the cracks of the GFRP could be caused by the impact work produced by the falling balls falling from all of another height,besides,the changing speed of the cracks increased with the falling height increasing.

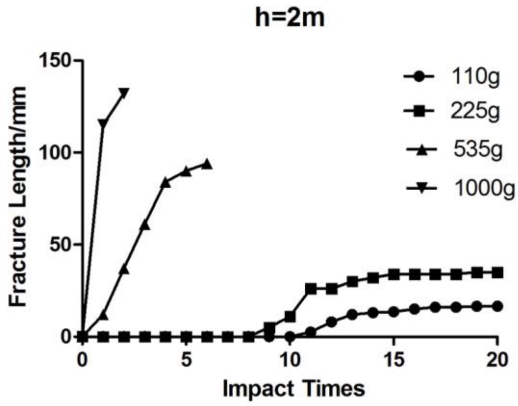
According to the experiment scheme,the trend diagram of the crack caused by the 20 impacts of the falling ball at different heights is shown in Figure 4.





(a) 0.22m (b) 0.45m



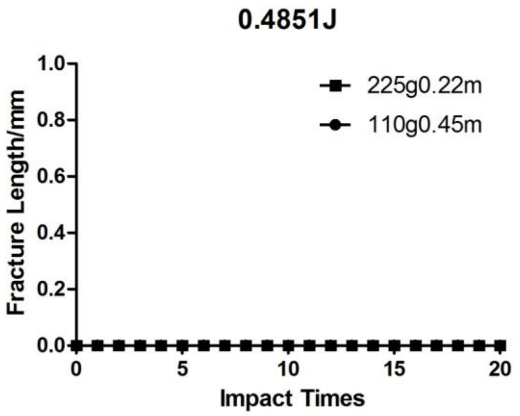


(c) 1.07m (b) 2m

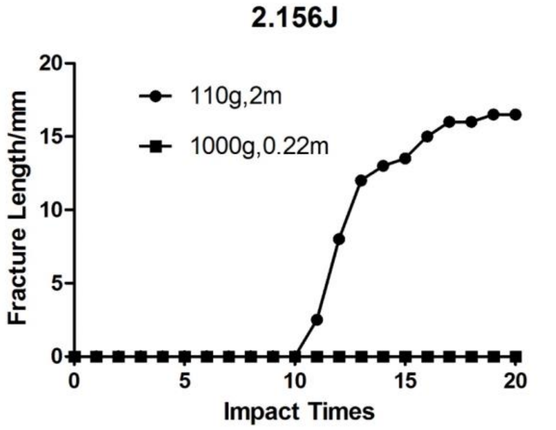
Figure 4. The cumulative development diagram of cracks at different heights under the impact of falling balls

In the Figure 4-a,when falling height of the falling ball was 0.22m,the impact work was so small that the cracks could not be caused by all mass of the falling balls in the GFRP.In the Figure 4-b,when falling height of the falling height of the falling ball was 0.45,impact crack in the GFRP could not be caused by the impact work produced by the falling ball of 110g and 225g.But the cracks caused by impact produced by the falling balls of 535g and 1000g occurred respectively at the 13th and 9th impact,and the trend of changing of both was approximately similar.In the Figure 4-c,when falling height of the falling height of the falling ball was 1.07m,accept the case of falling ball of 110g,the cracks of the GFRP could be caused by the impact work produced by the falling balls of another all mass,and the greater the mass of the falling balls was, the faster the velocity of crack development was.In the Figure 4-d,when falling height of the falling height of the falling ball was 2m,the cracks of the GFRP could be caused by the impact work produced by the falling balls of all mass,and the greater the mass of the falling balls was, the faster the velocity of crack development was.Among those falling balls,the velocitis of cracks development under the impact produced by the falling balls of 110g and 220g were approximately similar,and so were the falling balls of 535g and 1000g.But the above two have bigger difference.

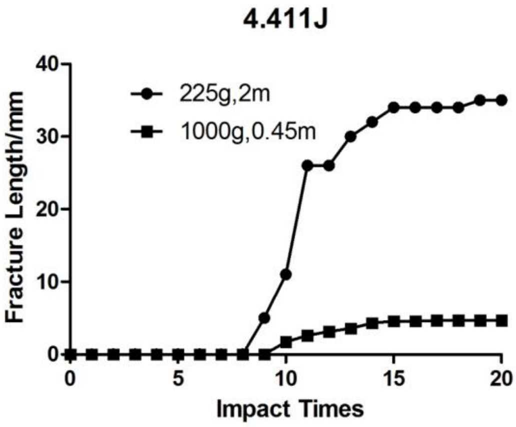
The trend diagram of the crack development caused by different reasons with different impact times under the same impact work was shown as the Figure 5.



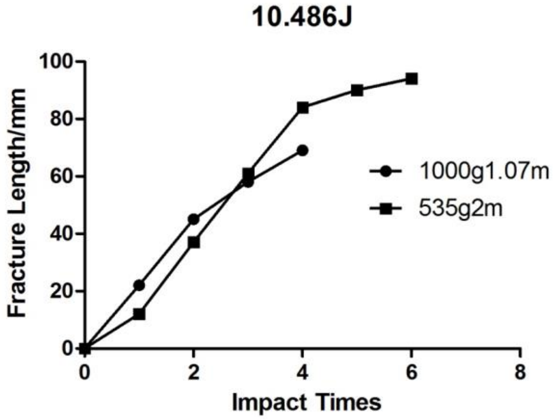
0.4815J



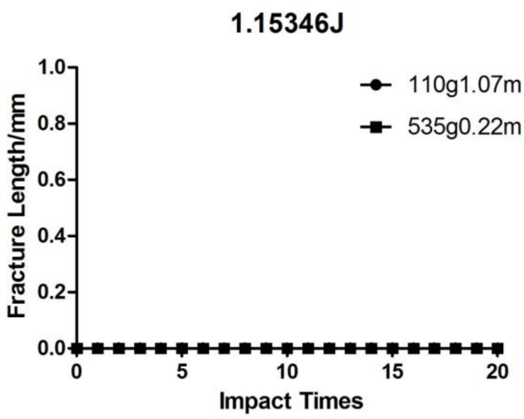
(b) 2.156J



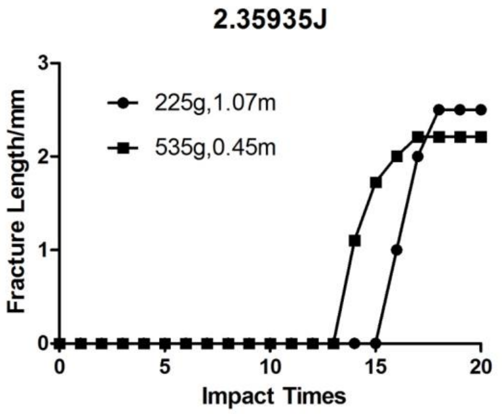
(c) 4.411J



(d) 10.486J



(e) 1.1531J



(f) 2.359J

Figure 5. The diagram of crack accumulation development of different reasons under the same impact work.

In the Figure 3(a)(b),the height of the ball release is low and the quality of the falling ball is smaller, therefore, the impact work is too small to cause the cracks in the GFRP .In the Figure 3(c),the mass of the drop ball dropping from the height of 2m is 110g, and the impact work is the same as the 1000g drop ball dropping from height of 0.22m,however,as the former drops higher, the impact velocity is more rapid. so it produces greater attack power and the damage it cause to glass fiber reinforced plastics is more obvious. Besides, a length of 16.5mm crack on the GFRP was caused by the former drop ball, but there was no cracks caused by the latter. In the Figure 3(d), the impact work caused by the 225g and 535g drop ball dropping from different heights was same, because the impact speed of the 225g ball is greater, the crack caused by it is longer than the 535g drop ball. Besides, because the mass of the latter is greater, the damage of the GFRP caused by the impact of it appeared earlier.In the Figure 5-e,it shows that when the impact of both of the falling balls of 225g and 1000g were 4.411J,the velocity of the 225g was faster,so the impact caused by it was greater,and the damage caused by it to GFRP was obviously bigger than that caused by 1000g ball.It shows in the Figure 5-f that in case the impact power is 10.4861J,the GFRP would be destroyed thoroghly by the lager ball before the smaller one,but the length of the crack was shorter.It showed by comparing this group of data that in case that the impact work was same,the taller height the falling balls fall from ,the longer the length of the crack in the GFRP caused them was.But in case that the crack could be produced,the GFRP could be destroyed thoroghly faster by the ball falling from higher place.

In order to discuss the reasons why the length of the crack was different under the same impact work,the analysis was carried out combining with the impact dynamic stress theory.Its derivation process is shown as formula(1):

$$\delta_{st} = (1+\sqrt{1+\frac{EHd^3}{288mgl^3}})\bullet\frac{3mgl}{d^2} \tag{1}$$

δ_{st} ——The maximum dynamic stress loaded on the center of the GFRP;

m——The mass of the impact steel ballk

d——The thickness of the GFRP;

l——The length of the GFRP side

E——The elastic modulus of the GFRP

H——The falling height of the impact steel ball

According to the above fomula,the dynamic stress value of the GFRP caused by different influences is shown in Table 2.

Table 2. Calculation table of dynamic stress (kPa)under different influence factors

Height/m \ Mass/kg	0.11	0.225	0.535	1
0.22	1294	2646	6292	11760
0.45	1876	3319	7045	12551
1.07	2383	3979	7891	13507
2	2942	47399	8932	14749

According to the above figures, the change of the GFRP dynamic stress caused by the change of the height of falling ball was greater than that by the change of mass of the falling ball under the same impact work.

4. Conclusion

(1)With the increase of the impact work of the falling ball, the development of the crack length was remarkable, and there is obvious linear relationship between the two. When the impact was below 2J,the obvious crack could not be observed because the energy was absorbed little.

(2)The impact of the falling ball can be changed by the increasing of the mass and the height of the ball.

(3)Combining with the impact theory, under the same impact, the effect of instantaneous velocity on the development of crack is obviously higher than that of falling ball. this is due to its greater dynamic stress.

(4)The effect of the impact under the different times has certain summative which is not the linear summative, and the development of the crack was caused by the sudden rupture after the fiber cloth absorbed the energy during the process of the impact.

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