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Application of PVDF Gauges in solid interface†

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Abstract: It's difficult to directly measure the pressure on the surface of the material in the impact process. The PVDF (Polyvinylidene Fluoride) gauges may help to solve the problem. In this paper, some split Hopkinson pressure bar(SHPB) experiments were carried out with the PVDF Gauges as specimens. And the strain gauges pasted on the bars are used as measurement method. By comparing the results of the strain gauges and the PVDF gauges, it is proved that there are stress concentration when the PVDF gauges were sandwiched directly in the solid interface. Then two methods to eliminate stress concentration are verified by experiments. The first method is adding cushion, such as electrical tape. The second method is using 502 glue, which is evenly coated on the interface.

Keywords: PVDF gauge; SHPB experiment; stress concentration; strain gauge

1. Introduction

In the study of mechanical properties of materials, the dynamic mechanical properties is becoming more and more important. Under dynamic conditions, it is difficult to measure the pressure on the solid surfaces directly. So it is necessary to design a sensor that can be directly attached to the material surface. PVDF as a new type of organic polymer material, has a strong piezoelectric effect after being polarized and can be fabricated into stress gauges, which have high piezoelectric coefficient, wide frequency response, thin lateral dimension, no need of external power supply, etc. Therefore, PVDF Gauges are expected to play a special role in the direct measurement of dynamic loads. Then, it is necessary to understand it's characteristics in solid interface.

As is known to all, the SHPB experiment is one of the effective methods to test the dynamic mechanical properties of materials, and the measurement technology is important. How to obtain the impact load of the specimen accurately? The traditional method is measuring the strain signal which are pasted on the bars. This is an indirect method. However, there is still no effective method for measuring the loads directly on the surface of the specimen. At present, PVDF Gauges have been used in dynamic experiments. And some of them have been commercialized. Graham R A and Bauer F [1] studied the maximum pressure of the PVDF Gauge in the air gun, and it was found that the test accuracy achieved 20GPa and the maximum was 35GPa. F. Bauer [2] applied the PVDF gauge to the SHPB experiments, and found the measured value was larger than the theoretical value because of the radial expansion after compression. Obara [3] applied the self-made PVDF gauge to calibrate the impact experiment, and the highest pressure was 1 GPa. Xi D Y [4] calibrate the PVDF piezoelectric film (the stress range was 0~80MPa) and obtained the relationship between the charge and the stress by SHPB experiments .Wu X T [5] found that the stress concentration appears if the area of PVDF gauge's sensitive part is less than bars base on SHPB device with bars of 37mm in diameter. And with decrease of the area of sensitive part, the stress concentration was more obvious. They obtained the dynamic piezoelectric coefficient k was equal to 29.05 pC/N, and pointed out that the value of k changes with the production process and work conditions. Pang Baojun [6] tested the sandwich type PVDF gauges on SHPB device, and found that the sensitive area was a very important factor. With the increase of the sensitive area , the measurement error decreases gradually, and the influence of stress concentration decreases. They calibrated the dynamic piezoelectric coefficient of PVDF gauges with a sensitivity area of 144 mm², and the k was equal to 24.46pC/N. Therefore, the PVDF Gauges have been proved to be used to directly measure the load in SHPB experiments. However, due to the need for the transformation of the stress and charge, the dynamic piezoelectric coefficients k should be calibrated in advance. And the work condition of k must be the same as the condition of the calibration process.

In most references, the PVDF gauges and strain gauges were combined to measure the loads. Then, can PVDF gauges measure loads directly for some special conditions, especially if the strain gauges and other measurement methods are not able to calibrate the PVDF gauges? In this paper, the stress concentration problem with PVDF gauges were verified by SHPB experiments, and two methods to solve the problem were proved to be possible.

2. Experimental methods

Figure 1 is the sketch of the SHPB experiment with PVDF Gauges. The strain signal can be obtained by the strain gauges which were pasted on the incident and transmission bars. The PVDF Gauge is placed between the incident bar and the transmission bar. Under the impact pressure, the PVDF gauge will generate electric charges on both sides of the electrode. The voltage of resistance that parallel connecting to the PVDF gauge can be measured, and the current flowing of the resistance can be obtained. Then the charge amount can be obtained by integrating the current flowing. Finally, the load is calculated by the relationship between the charge and the load.

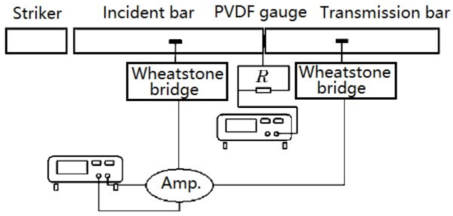

Figure 1. Sketch of SHPB experiments with PVDF Gauges

According to the one-dimensional stress wave theory, the elastic wave in one-dimensional stress state is not distorted when propagating in the bars. Therefore, it can be considered that the SHPB system is one-dimensional. In the SHPB experiment, the strain gauges were pasted on the bars, and the strain signal was measured. Then the contact load in the interface of the two bars was obtained. This is a mature method, and lots of experiments have proved the correctness and accuracy of this method. Therefore, it can be considered that the strain gauge method can obtain the "truth value" of the loads in the bars. Therefore, both strain gauges and PVDF gauge were applied in the same experiments. If the two results are the same, it can be determined that the PVDF gauge is accurate and reliable. If not, it indicates some problems exists when PVDF gauges used for measuring load in the solid interface. Then, it is expected to be corrected by some means.

3. Experiments with PVDF gauges

The experiments were carried out on the SHPB device with aluminum bars in diameter of 25mm. Both bars are 1400mm long. And the striker is 500mm long. Additionally, we also used electrical tape, which has strong anti-pressure ability, not easy to deform, and extremely uniform thickness. Three kinds of tapes were used, and the thickness was 0.02mm, 0.056mm and 0.081mm respectively. Combining different thickness of tape can obtain more different thickness.

In experiment 1, the PVDF gauge was directly sandwiched between two bars. In experiment 2, the area around PVDF gauge was filled with PVDF gauges. In experiment 3, the base around sensitive area was removed. As shown in figure 2.

Figure 3 is the experiment results. It can be found that the stress pulses in the incident bar and transmission bar obtained through the strain gauges are the same, and the average stress is about 84MPa. This also indicates that the PVDF gauge effect nothing on the stress pulses in bars. In three experiments, the stress pulse width measured by PVDF gauges are exactly the same as that of the strain gauges, but the amplitude are different. The measured values of the three experiments are 172MPa, 147MPa and 400MPa respectively. Compared with the stress in the bar, it is 2.0 times, 1.8 times and 4.8 times respectively.

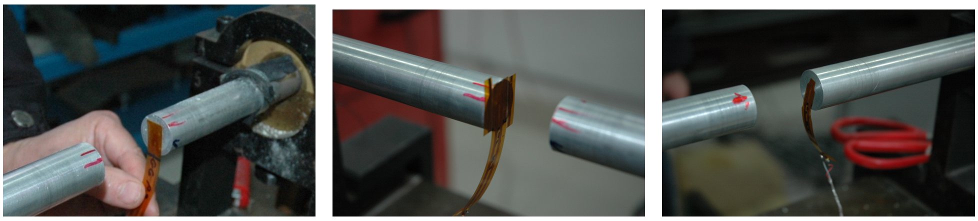

Figure 2. Experiments with different work conditions

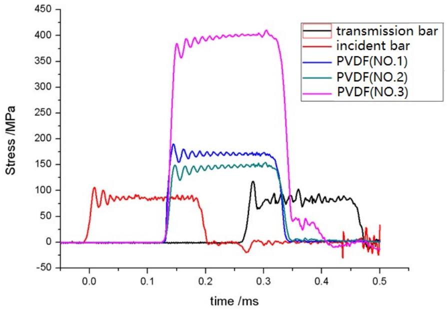

Figure 3. Experiment results of strain gauge and PVDF gauges

Thus, it can be seen that the PVDF gauge sandwiched the two solid interfaces generates higher pressures than the actual situation. And the smaller the area of the sensitive area, the higher the pressures. This is precisely because the PVDF has a certain thickness, forming a physical bulge between the flat solid interface, which inevitably leads to the stress concentration.

In experiment 4, the PVDF gauge was pasted with rectangular electrical tape with a thickness of 0.324mm and a width of 6.0mm. Experiment 5 is based on experiment 4, but both sides of the gauge are filled with electrical tape of thickness of 0.081mm, as shown in figure 4.

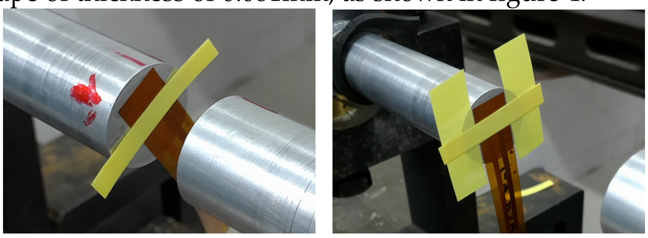

Figure 4. Experiments with different work conditions(by adding tape)

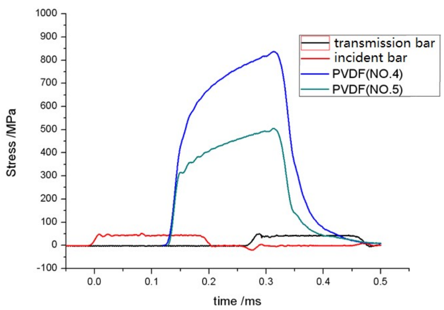

Figure 5. Experiment results of strain gauge and PVDF gauges(by adding tape)

Figure 5 is the experiment results. It can be seen that the stress signal in the incident bar and transmission bar is nearly the same, about 42MPa. However, the shape of the signal measured by

PVDF gauges are different from that of strain gauges. The stresses measured by PVDF gauges in both cases is 836MPa and 501MPa, about 20 times and 12 times of the stress in the bars.

The experiment results show that the stress concentration can be generated by placing PVDF gauge directly between the two solid interfaces. With the change of the hardness of the material, the PVDF test results are not identical, and there is no obvious quantitative regularity. It shows that there are strict requirements when the PVDF gauges were used directly in the solid interface to measure the loads.

4. Methods to eliminate stress concentration

Since the reason of stress concentration is the physical bulge formed by the PVDF gauge. Therefore, the primary way is to use something filling the area around the PVDF gauge. The first method is adding cushion. And the second method is adding 502 glue(cyanoacrylate adhesive).

3.1. Adding cushion

Use electrical tape as a cushion, and put the cushion around the PVDF gauge. And then sandwiched them between two bars. As shown in figure 6. Depending on the pressure, different thickness of the cushion can be used.

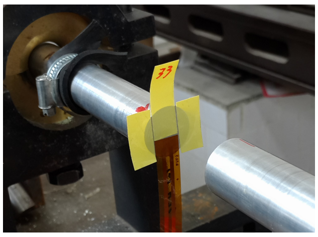

Figure 6. Adding cushion to eliminate stress concentration

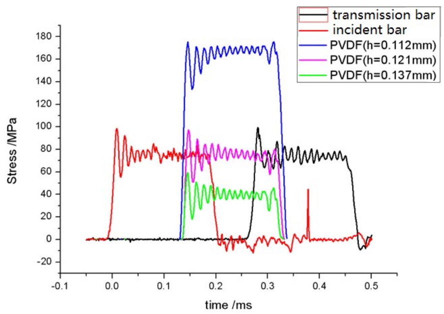

Figure 7. The effect of cushion with different thickness

Figure 7 shows the effects of different thickness cushion. It can be seen that the stress in the bars are 78MPa. The stress pulse width measured by PVDF gauge are the same as that of the strain gauge, but the stress amplitude are about 170MPa, 78MPa and 40MPa respectively, when the thickness of cushion are 0.112mm, 0.121mm and 0.137mm. It can be seen that the cushion thickness has obvious influence on the measurement value of PVDF gauges. The thicker the cushion, the lower the measurement value. When the thickness of the cushion is 0.121mm, the measurement value of the PVDF gauge is consistent with that of the strain gauge. In addition, you can assume that when you increase the thickness of the cushion, the measurement values will go down further, even to zero.

When the stress in the bar is 40MPa, the PVDF gauge measurement value is 38MPa with the thickness of cushion is 0.112mm. When the stress in the bar is 100MPa, the PVDF measurement value is exactly the same as the strain gauge when the thickness of cushion is 0.132mm. As shown in figure 8.

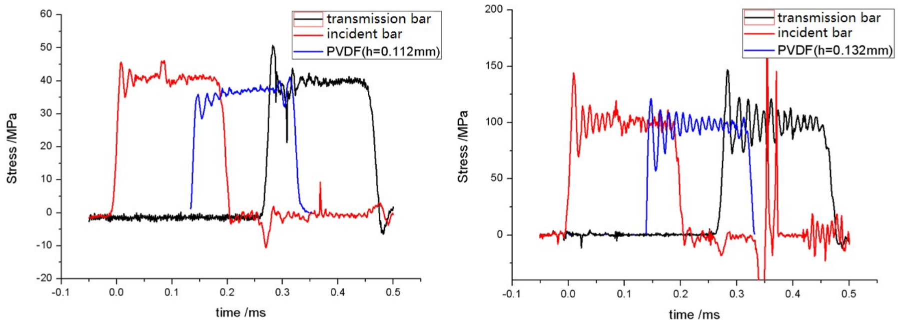

Figure 8. Different thickness of cushion layer to eliminate stress concentration

It can be seen that the method of adding cushion can completely eliminate the stress concentration. However, the problem is that the cushion thickness cannot be selected in the case of unknown loads. This will make it difficult to use PVDF gauges directly. Therefore, if the load can be estimated in advance, the method can still be used to obtain the approximate load.

3.2. Using 502 glue

When placing PVDF gauges directly between the two bars, the stress on the bar was 79MPa and the PVDF gauge measurement value was 285MPa. Another situation, The PVDF gauge is placed in the center of the bar end, and the 502 glue is evenly coated on the gauge and the whole bar end surface. Wait and until the two bars are fixed and glued. Now, the measurement value of PVDF gauge is 85MPa, which is similar to the stress in the bar. As shown in figure 9.

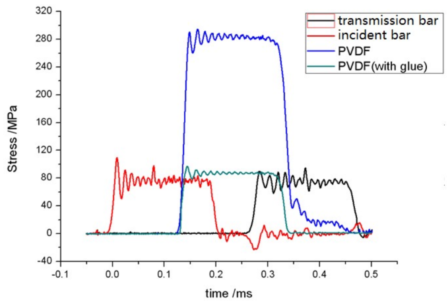

Figure 9. SHPB experiment results (with and without 502 glue)

The same experiments were performed on the SHPB device with a diameter of 120mm. When 502 glue was not used, the average stress on the bar was 145MPa and the value test by PVDF gauge was 375MPa. Using 502 glue, the stress on the bar was 65MPa, and the measured stress of PVDF gauge was about 65MPa, which was exactly the same. The test results are shown in figure 10.

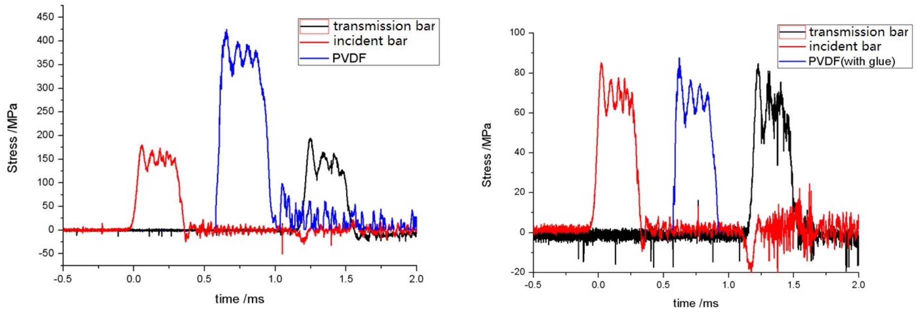

Figure 10. SHPB experiment results (Bars in diameter of 120mm, with and without 502 glue)

Thus, the stress concentration can be eliminated well when the 502 glue is evenly coated on the gauge and the whole bar end surface. The reason is that 502 glue is equivalent to a cushion, and the load acting on the PVDF gauge and the cushion evenly. So the 502 glue effectively eliminate the interface physical bulge by PVDF gauge, and the stress concentration disappeared.

5. Conclusions and discussions

In this paper, the SHPB experiments are carried out with the PVDF gauges sandwiched between two bars. The loads were measured by strain gauges and PVDF gauges. The experiment results were compared and analyzed. According to the analysis, it is as follows:

1)There is stress concentration when the PVDF gauge is sandwiched between the solid directly. The measured value is higher than actual situation. When interface characteristics changed, the experiment results of PVDF gauge are also changed. Therefore, if the PVDF gauges are used individually, stress concentration must be eliminated.

2)The method to adding cushion can eliminate stress concentration well, but it is difficult to determine the thickness of the cushion before the experiment. Therefore, if it is unavoidable to use cushion, it is better to estimate the magnitude of the load in advance to determine the thickness of the cushion. In this case, the approximate value can be obtained by PVDF gauge;

3)When using PVDF gauge to directly measure the load in solid interface, it is a good method to use 502 glue to eliminate the stress concentration.

In addition, the PVDF gauges must be kept even enough during the whole impact process. Any deformation of PVDF gauges may generate abnormal experiment results.

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