 CMC, vol.21, no.2, pp.107-117, 2011

Study on Shear Test of New Style Automotive Structural Adhesive using Digital Image Correlation Method

Bin Li[1], Guo-biao Yang[1], Qi-rong Zhu[2] and Fan Ni[2]

Abstract: In this paper, digital image correlation method (DICM) is employed to measure the shear behavior of the spot welding specimens and the ones using adhesive under quasi-static lap shear testing. The images of the specimens' surfaces are captured in real-time by CCD and corresponding computer system. DICM is subsequently used to obtained strain by correlating the images captured before and after deformation. Then, both force-displacement curves and stress-strain curves of the specimens including the cracking load are obtained. The results and analysis show that the mechanical properties of specimens using adhesive compared with the spot welding specimens have an obvious advantage. This paper provides some experimental basis for improving this new type of structural adhesive. In this experiment, the method of non-contact measurement was used to obtain the strain. It has greater significance.

Keywords: Automotive structural adhesive, Shear test, DICM, Non-contact measurement

1 Introduction

Spot welding is the most important welding method in automobile industry. It has been widely used in automobile industry, because of its high efficiency, ease of automation. According to statistics, every car required approximately 3000 spot welds during their production [Mao, Zhang and Tadashi (2003)]. Indispensable as spot welding seem to be, it has its drawbacks. For example, welding cracks are the most common defect which will greatly affects the safety of spot welded structures. In order to minimize this influence, it is very important to improve the welding craft and structure design of welding joint [Liu , Yang, Shi and Dong (2006)]. But the welding cracks are inevitable. Automotive structural adhesive is novel cement-

[1] School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai, China
[2] Paradigm Center of Mechanics Laboratory of Ministry of Education, Tongji University, Shanghai, China

ing material which is be used for bonding, sealing, encapsulating of metal, glass, plastic etc., with high shear strength and excellent adhesive strength. With the development of science and technology, there has been a trend toward using structural adhesive to replace spot welding because of its particular advantage. Therefore, the study of the mechanical properties of the automotive structural adhesive is a subject worthy of the research field and the practice field.

In this paper, digital image correlation method (DICM) is employed to measure the shear behavior of the spot welding specimens and the ones using adhesive under quasi-static lap shear testing. The images of the specimens' surfaces are captured in real-time by CCD and corresponding computer system. DICM is subsequently used to obtained strain by correlating the images captured before and after deformation. Then, both force-displacement curves and stress-strain curves of the specimens including the cracking load are obtained. Based on the techniques of digital image processing and analysis, the method makes accurate measurement of target displacement from film image sequences. It has many advantages over other measuring methods, such as non-contact measurement, wide range, high measuring precision, high working efficiency and easy operating, etc., so having certain application value.

2 Principles and experimental method

Based on the techniques of digital image processing and analysis, the method makes accurate measurement of target displacement from the image sequences. Along with the rapid development of computer technology, it is possible to get the pixel values within image by computer programs. Digital image correlation method is used primarily for measuring the in-plane deformation of object. Sub-pixel measurement accuracy is about 0.01 pixels. Generally speaking, CCD Image-Input System can acquire the images with the resolution of 768×576. When the ranging scale inside 10mm, the method can control the error on 10000μm/76800 0.1302μm even little. This is the theoretical accuracy of the digital image correlation method. Considering the rotation of CCD image planes, the depth difference in object space, the distortions of an optical system and so on, the measurement precision of the DICM can reach 1μm in actual measurement [Yang, Fang, Ding and Gao (2000)].

DICM, as one of a new measuring technology, arouses more and more attention by the virtue of non-contact measurement, wide range, high measuring precision, high working efficiency and easy operating, etc [Sun, He, Xu and Luo (2007); Yang, Zhu, Zhang and Wu (2007); Peters and Ranson (1982)].

The definition of correlation is mutual relationship or connection between two or more things. The degree of correlation can be represented by the formula as follows:

$$\rho = \frac{E\left[(x-E_x)\times(y-E_y)\right]}{\sqrt{D_x \times D_y}} \tag{1}$$

where ρ is coefficient of association,E_x,$D_x$is respectively the expectation value and variance of x. Similarly, E_y,$D_y$is respectively the expectation value and variance of y.

In order to simplify the task of calculation, another formula is used in actual application, and it can be shown as follows [Yang, Zhu, Lu and Yu (2006)]:

$$\rho = \frac{E_{xy} - E_x E_y}{\sqrt{D_x \times D_y}} \tag{2}$$

where E_{xy} is the expectation value of $x \cdot y$.

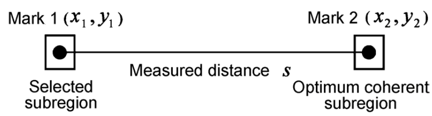


Figure 1: The sketch map of two markers on the measured object.

The necessary steps are: Firstly, the images including the measured object are collected and stored in memory during the deformation process. Secondly, the sub region in which the Mark1 is included is chosen. The sub region can be described with the gray value matrix in computer. Thirdly, we get the outlines of the Mark1 through the method of the image threshold segmentation, and acquired the gray value of Mark1. The center of it can be identified. Then, we can do a correlation searching calculation in the same image according to a certain step length, and then, another mark, the Mark2, will be found. The two marks have higher correlativity than any other ones. The sketch map of two markers on the measured object is shown in Fig.1. If we choose a large step length, the speed of searching is obviously improved, but the search accuracy decreases. If, on the contrary, we choose a small step length, the search accuracy is obviously improved, but the speed of searching drops. So, the searching algorithm is important. In this research, we choose the variable step length adaptive Algorithm which can effectively increase the searching speed but keep search accuracy at the same time. Then, we get the distance between the two marks using the Euclidean distance formula, which is show as follow:

$$s = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{3}$$

where (x_1, y_1) is the center point of the Mark1, and (x_2, y_2) is the center point of the corresponding mark that is the Mark2. The unit of the distance is pixel. Though the measuring scale, the actual distance can be obtained. Finally, the mean deformation can be obtained at a given time by subtracting the distance of the two center point of the marks in undeformed image from the one which is in the deformed image at this time. The mean strain at this given time is defined as:

$$\varepsilon = \delta / L \tag{4}$$

where δ is the mean deformation at this given time, and L is the distance before the deformation.

3 Equipment and Procedures

The CSS-100 electric universal testing machine are used in this test. The load capacity is 100KN, and the deformation measurement accuracy is±0.5%. The crosshead speed range is 0.01˜mm1000mm/min in stepless. The speed is 10mm/min in this test.

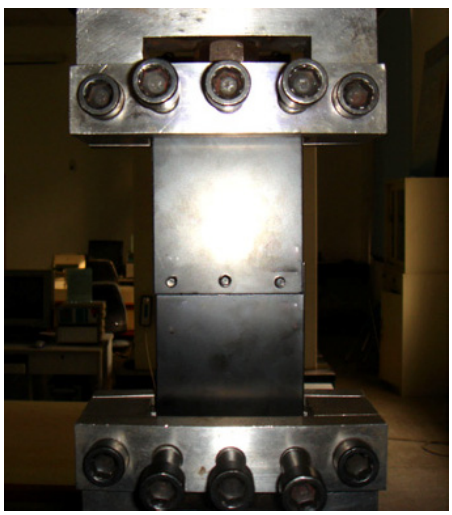


Figure 2: The test fixture.

The test fixture and specimen are shown in Fig.2˜Fig.5. Fig.6 is sketch map of the marks.

In this experiment, the digital image acquisition system which is mainly composed of optical imaging device, optical-electrical converter and digital image processing

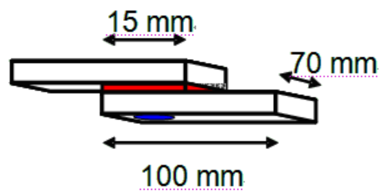


Figure 3: The specimen.

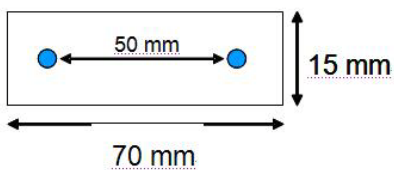


Figure 4: The overlap of two spot welds.

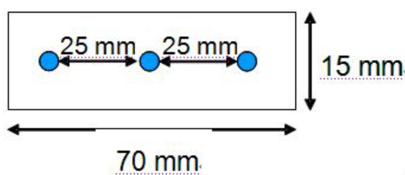


Figure 5: The overlap of three spot welds.

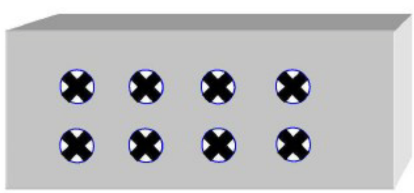


Figure 6: The marks.

system are used, as shown in Fig.7. Through this system,the images including the measured object and the marks are collected and stored in memory and saved as BMP image formats during the deformation process. In order to obtain clear im-

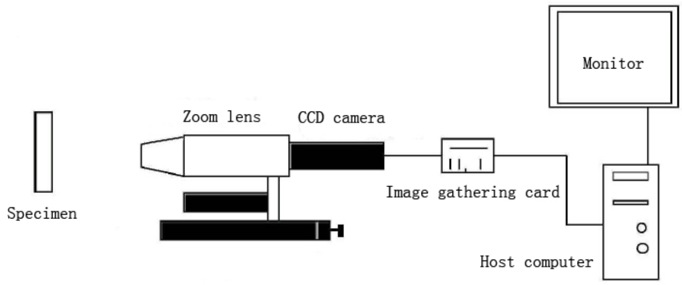
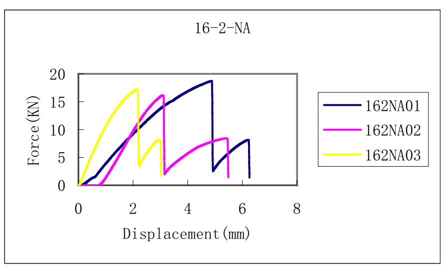


Figure 7: The digital image acquisition system.

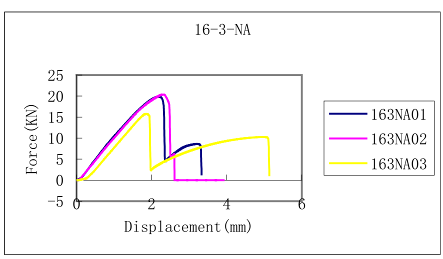
ages, the precision three-dimensional adjuster is used to support the CCD camera. Natural daylight is adopted in this experiment.

4 Experimental result and discussion

4.1 The shear testing result of spot welding specimens

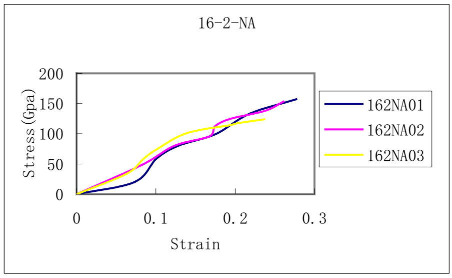


(a) 16-2-NA.

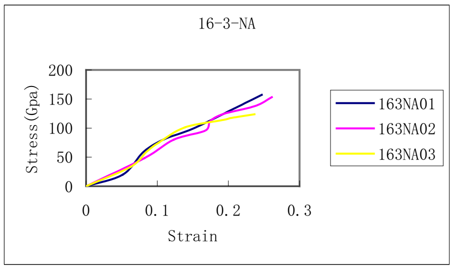


(b) 16-3-NA.

Figure 8: The relation of force and displacement (16-2-NA, 16-3-NA).



(a) 16-2-NA.



(b) 16-3-NA.

Figure 9: The relation of force and displacement (16-2-NA, 16-3-NA).

Table 1. The test result data of 16-2-NA and 16-3-NA.

		Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation
16-2-NA	Breaking Strength (MPa)	98.51	85.09	90.53	91.37	5.510279
	Ultimate Shear (KN)	18.71	16.16	17.20	17.36	1.046885
	Mean Fracture Strain (με)	213025				
16-3-NA	Breaking Strength (MPa)	69.70	71.46	55.30	65.49	7.238979
	Ultimate Shear (KN)	19.86	20.36	15.76	18.66	2.062783
	Mean Fracture Strain (με)	248230				

16-2-NA, 16-3-NA: The 16 stands for the thickness of the backing, the 2, 3 stands for the number of the spot welds, the NA stands for the spot welding specimens.

4.2 The shear testing result of the specimens using adhesive

It can be seen from Table 1 that the stress of spot welding specimens is improved remarkably by increasing the number of spot welds in them. The ultimate shear value of specimens has increased to 18.66KN from 17.36KN.The breaking strength

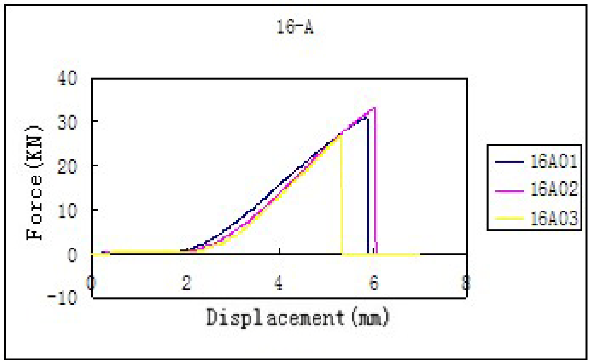


Figure 10: The relation of force and displacement (16-A).

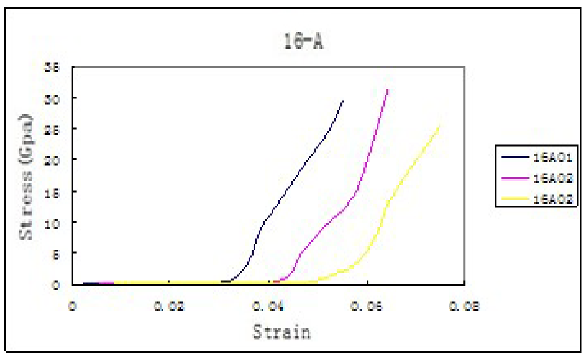


Figure 11: The relation of stress and strain (16-A).

Table 2. The test result data of 16-A

		Specimen 1	Specimen 2	Specimen 3	Average	Standard Deviation
16-A	Breaking Strength (MPa)	29.58	31.63	25.68	28.96	1.424015
	Ultimate Shear (KN)	31.06	33.20	26.96	30.41	1.495216
	Mean Fracture Strain (με)	64943				

16-A: The 16 stands for the thickness of the backing, the A stands for the specimens using adhesive.

has decreased to 65.49MPa from 91.37MPa.The mean fracture strain of them is close. The change is caused by the different structure of specimens. The specimens are made from two thin, flat strips of high-tensile steel material called backing, with spot welds on the overlapping ends as shown in Fig. 3.Based on the failure theory of structure in mechanics of materials, we know that a failure will be first initiated in a weak spot on the structure if the material fails at this time. In this test, the weak spot on the specimens are spot welds on the overlapping ends. Under load conditions, the stress concentration of spot welds increases with greater force on the ends of the backing. The damage in the spot welding specimens happens when the applied shear stress is more than a certain extent, and the damage value increases remarkably with stress.

Along with the increase of spot welds, the ultimate shear has increased. It can be seen from Fig.12, the failure are first initiated in spot welds on the overlapping ends which have a large plastic deformation. The rest of the backing is insufficiently utilized.

There are many reasons for this phenomenon, but the defective workmanship is the most significant reason. The backing on the overlapping ends has the welding defect to a different extent because of welding work. This can be seen from Table 1: the dispersion degree of the specimens' test results was great at the parallel test. Their unpredictable the welding defect has become a potential threat to the safety of welding structure.

It will be observed from the Table 1 and Table 2 that the ultimate shear value of adhesive specimens has increased to 30.41KN. It is increased by 63%, but the breaking strength has decreased to 28.96MPa. This is because the stress state of joint can be improved by using adhesive on the overlapping ends. On the overlapping ends of the backing, the shearing area of the adhesive specimens is larger than the spot welding specimens, so the stress concentration decreases. This improves whole performance of the structure greatly. The fracture surfaces of the specimens with the structural adhesive-bonded joints are shown in Fig.13. In this test, the weak spot on the specimens is the structural adhesive-bonded joints. The failure is first initiated in structural adhesive, and the backing doesn't have a large plastic deformation, so the backing is sufficiently utilized. This experimental result indicates that adhesive strength is very high, but the ultimate shear value is relatively lower. The ultimate shear value of adhesive specimens will be further improved, providing the shearing resistance of the structure adhesive improved.

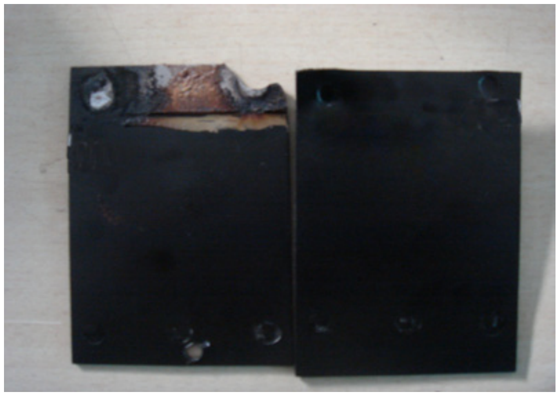


Figure 12: The fracture surfaces of the specimens with the spot welding-bonded joints.

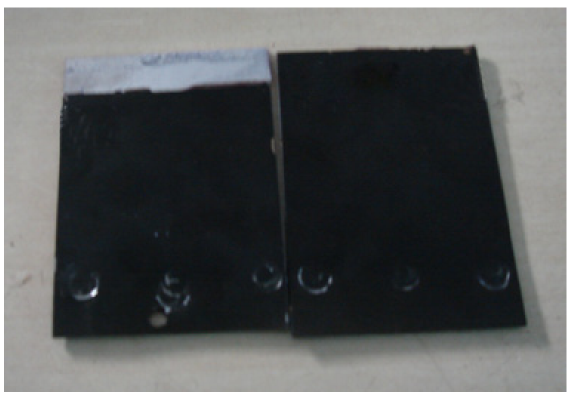


Figure 13: The fracture surfaces of the specimens with the structural adhesive-bonded joints.

5 Conclusion

In this paper, digital image correlation method is employed to measure the shear behavior of the spot welding specimens and the ones using adhesive under quasi-static lap shear testing. The results and analysis show that the mechanical properties of specimens using adhesive compared with the spot welding specimens have an obvious advantage, but the shearing resistance of the structure adhesive still need to be improved. This paper provides some experimental basis for improving this new type of structural adhesive.

In this experiment, the method of non-contact measurement which is digital image correlation method is used to obtain the strain. It has many advantages over other measuring methods, such as non-contact measurement, wide range, high measuring precision, high working efficiency and easy operating, etc., so having certain application value in actual application. Its precision meets the needs of engineering practices.

Acknowledgement: The authors would like to thank the researchers of modern test technology placePlaceNameResearch PlaceTypeInstitute PlaceNameTongji PlaceTypeUniversity. The investigation was also supported by the National Natural Science Foundation under Grant No. 10972160.

References

Liu Zhaowei; Yang Lijun; Shi Caiyun; Dong Tianshun (2006): Advancement and trend of monitoring control in resistance spot welding, *Electric Welding Machine*, vol. 36, no. 9 pp. 1–3.

Mao Lanqun; Zhang Dun; and Tadashi Sotomura (2003): Mechanistic study of the reduction of oxygen in air electrode with manganese oxides as electrocatalysts, *Electrochimica Acta*, vol. 48, no. 8, pp. 1015–1021.

Peters W. H; Ranson W. F (1982): Digital imaging techniques machanics, *Opt. Eng*, vol. 21 no. 5, pp. 427–431.

Sun Wei; He Xiaoyuan; Xu Ming; Luo Bin (2007): Study on the tension test of membrane materials using digital image correlation method, *Engineering Mechanics*, vol. 24, no. 2, pp. 34–38.

Yang Guobiao; Fang Ruhua; Ding Zuquan; Gao Jianxin (2000): Analysis for measurement precision of Projection Speckle Correlation Method (PSCM) , *Journal of Experimental Mechanics*, vol. 15 no. 2, pp. 2 240–245.

Yang Guobiao; Zhu Qirong; Lu Ronglin; Yu Tao (2006): Measurement of the Inside Diameter of Cylinder for Diesel Engine with Digital Correlation Method, *Acta Metrologica Sinica*, vol. 27 no. 1, pp. 2 2–24.

Yang Guobiao; Zhu Qirong; Zhang Zhang; Wu Kui (2007): Research on Equipment of Digital Speckle Correlation Method, *Modern Scientific Instruments*, vol. 1, no. 6, pp. 89–91.