



A Comparative Study of Local Heat Treatment for Enhancing Overall Mechanical Properties of Clinched Joints

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Clinching technology is widely used for joining lightweight materials. It is well known that the fatigue life of clinched joints is outstanding, but its static strength is inferior to other conventional joints such as resistance spot welding joints. In this study, a post-processing method was proposed to enhance the overall mechanical performances of clinched joints in material of steel plate cold commercial steel. Based on the failure mechanism analysis, we performed quenching, a local heat treatment process, on the joining zone to improve the static strength of clinched joints. The static strength and fatigue life of clinched joints before and after quenching were compared via experimental study. The experimental results showed that the tensile–shearing strength of clinched joint increased by 60.65% and the fatigue life was extended when the joint was under high fatigue load levels after local heat treatment. Besides, metallographic test and fracture analysis were conducted to analyze the mechanism of the change of mechanical behaviors. Lath martensite was observed in the cross section of clinched joint after local heat treatment, which is the main reason for the tensile–shearing strength increase as martensite has higher strength than ferrite and pearlite. The fracture analysis showed that the fatigue fracture mode became transcrystalline rupture after local heat treatment when the clinched joint was under low fatigue load levels, which lead to the fatigue behavior of clinched joints weakened. Nonetheless, the overall mechanical properties of clinched joints were improved.

Keywords clinched joints, fatigue, local heat treatment, mechanical properties, tensile–shearing

1. Introduction

The usage of lightweight materials has increased rapidly in recent years in the fields of aviation and automobile manufacturing because the issues of environmental pollution and energy shortage are becoming severer (Ref 1–5). However, most of the lightweight materials cannot be jointed efficiently by conventional welding techniques because of their high conductivity and low melting point (Ref 6, 7). Therefore, a series of advanced joining techniques were developed such as friction stir welding (Ref 4, 8), self-piercing riveting (SPR) (Ref 9), and clinching (Ref 10). Among the referred advanced joining techniques, clinching has drawn considerable attention in the past few years on account of its advantages and even became a relatively new branch of mechanical joining techniques. The technique of clinching has been investigated by numerous scholars from different aspects.

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First of all, the clinching process and static behavior of clinched joints were studied through numerical or experimental approaches. Mucha et al. (Ref 3) investigated the effect of clinching process parameters on the quality of joints via finite element analysis. The results indicated that the die groove width was the most critical parameter for the material flow and energy consumption during the joining process. Lambiase et al. (Ref 11) investigated the static behavior of clinched joints produced with fixed and extensible dies with different forming forces. The results showed that the clinched joints produced by extensible die have higher strength in the peeling test compared with the fixed one, but they have similar behavior in single-lap-shear tests. The material flow of clinching process with extensible dies was analyzed by finite element model by Lambiase et al. (Ref 12).

Besides, the fatigue property of clinched joints has also drawn significant attention. The earliest study on fatigue behavior of clinched joint was conducted by Carboni et al. (Ref 13) in 2006. Abe et al. (Ref 14) compared the fatigue behavior of clinched joints and resistance spot welding in ultra-high-strength steel sheets, which displayed the clinched joint that outperforms resistance spot welding joint. The fatigue performance of SPR and clinched joints in lap-shear specimens was investigated by Su et al. (Ref 15), who found that clinching has better fatigue endurance than SPR. In the meantime, Su et al. proposed a model to estimate the fatigue endurance of SPR and clinched joints. The fatigue strength of clinched joints in steel plate cold commercial (SPCC) steel was investigated by Kim (Ref 16) through experimental work and finite element model (FEM) analysis. Furthermore, the failure mechanism of clinched joint was another research hot spot. Recently, Lambiase et al. (Ref 17) proposed a numerical model to evaluate the fracture damage during the joining operation. Lei

et al. (Ref 18) proposed a forming factor to predict the fatigue failure modes of clinched joint.

The fatigue studies exposed that the fatigue property of clinched joint is outstanding compared with traditional joints like spot welding (Ref 19, 20) and even SPR (Ref 21). Nonetheless, the static strength of clinched joints is weak than conventional joints. Therefore, some improved clinching processes were developed to enhance the overall properties of clinched joints. A decent review about recent development of improved clinching processes was presented by Peng et al. (Ref 22).

All in all, the improved clinching processes can be categorized as hybrid clinching and modified clinching. Particularly, hybrid clinching technology is conventional clinch combining with other joining technologies; modified clinching technology is optimizing material flow in clinching process by enhancing clinching tools (Ref 22). The most common hybrid clinching process is clinch-bonding technology. Clinch-bonded hybrid joints were tested by Lei et al. (Ref 23). The results indicated that the shearing and peeling strength of the hybrid joint increased significantly. Zhang et al. (Ref 24) designed a novel clinching technique by combing clinching with resistance spot welding, which was called resistance spot clinching (RSC). RSC joint has been proved with superior tensile property compared with clinched joint. For the modified clinching technology, Chen et al. (Ref 25) proposed three reforming processes to reform clinched joint for the purpose of increasing its strength. Recently, optimization approaches for clinching tool have been proposed by Wang et al. (Ref 26) and Schwarz et al. (Ref 27). Using the optimized clinching tool, the quality of clinched joints was apparently improved, and therefore their physical properties were significantly enhanced.

However, rarely this study paid attention on improving clinched joints' physical properties after the joining process. In this study, based on the analysis of clinched joints' failure modes, a novel approach is proposed to enhance the comprehensive performance of clinched joints. The effectiveness of the proposed method is evaluated by experimental study.

This paper is organized as follows: section 2 presents the details of experiments. Then, experimental results and corresponding analysis are followed in section 3. A discussion about the experimental results is presented in section 4, and the conclusion is drawn in section 5.

2. Experimental Procedure

2.1 Material Parameters

The steel plate cold commercial (SPCC) steel, which was widely used in the car body manufacturing of automobile, was employed in this study. If this post-processing method is effective, it can be extended to clinched joints in other materials. The chemical compositions of SPCC steel are given in Table 1, and its mechanical properties are presented in Table 2. The thickness of the jointed steel sheet is 1.0 mm, which was cut in the dimension of 110 mm × 20 mm.

Table 1 Chemical compositions of SPCC (%)

C	Mn	P	S	Al	Fe
0.04	0.25	0.01	0.005	0.05	Balance

2.2 Specimens Preparation

The configuration of the single-lap clinched joint is presented in Fig. 1. All specimens of clinched joints were produced with a cycle extensible die on a clinching equipment in model of RIVCLINCH 1106 P50. The employed clinching machine and tools are shown in Fig. 2.

As referred earlier, the main purpose of this paper is to investigate the influence of local heat treatment of joining zone on mechanical performances of clinched joint. Considering the forming mechanism (Ref 3) and failure modes (Ref 18) of clinched joints, quenching is selected as the heating process to enhance the strength and rigidity of the substrates in the joining zone, which has the possibility to improve the mechanical performance of clinched joints in steel. A heating platform was constructed to fulfill the local heating process, as shown in Fig. 3. The joining zone was heated to 870-885°C, which was measured by an infrared thermometer. Then, the heated specimen was immediately cooled to 20°C in 7% saline water. The choice of this technology for heating processing is determined by the components of the substrates. Fifty specimens were manufactured and categorized equally into two groups. One group was treated with local heated, and the other one performed as the reference set. An example of clinched joints before and after local heat treatment is presented in Fig. 4.

2.3 Tensile–Shear and Fatigue Tests

The clinched joints were tested on a material test system (MTS, Landmark 100 Servo hydraulic Test System). The

Table 2 Mechanical properties of SPCC

Young's modulus, GPa	Tensile strength, MPa	Shearing strength, MPa	Yield strength, MPa
210	650	445	550

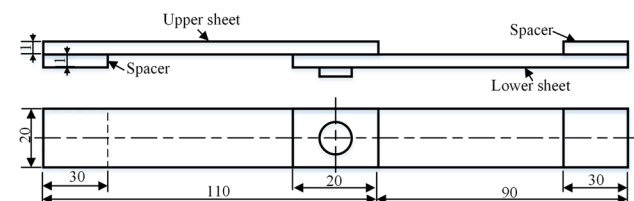


Fig. 1 Specimen configuration



Fig. 2 Clinching machine and cycle extensible die clinching tools

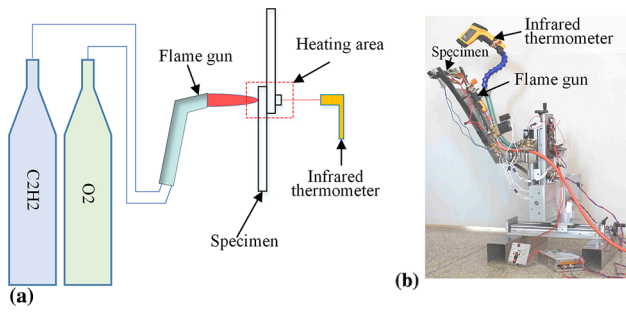


Fig. 3 Heating platform: (a) schematic; (b) photograph

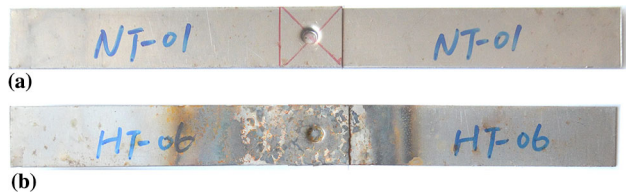


Fig. 4 Clinching specimen: (a) before local heat treatment; (b) after local heat treatment

tensile–shear strength of clinched joints before and after local heat treatment was tested. The tensile–shear test was performed under a constant tensile speed of 5 mm/min in machine’s tensile–shear mode, which can be considered as a quasi-static load. There are twelve specimens tested for each category of clinched joints.

Afterward, fatigue tests were conducted on the same MTS machine by setting different load levels based on the peak loads acquired in the static tensile–shear tests. The cyclic fatigue load was a sine waveform in the tension–tension mode with a load ratio of 0.1, and the frequency for the sine wave was 10 Hz. For load levels during the fatigue tests, the clinched joints without heat treatment were tested under 90, 80, 75, 65, and 60% of the average peak tensile–shear load; the clinched joints after local heat treatment were tested under 80, 70, 50, 37, 33, and 30% of the corresponding average peak load of tensile–shear test results. Each load level of the fatigue test was repeated three times. The fatigue load levels were determined by trying different loads on the tested specimen to obtain a reasonable fatigue life, which is started from a high load level and decreased to a load that the fatigue cycle can reach two million.

Besides, two spacers were utilized to reduce the additional bending load during the statics tensile–shear and dynamic fatigue tests, as shown in Fig. 1. The experimental results are presented and discussed in sect. 3.

3. Results and Analysis

3.1 Statics Property

3.1.1 Tensile–Shear Strength. The experimental results of tensile–shear test are presented in this subsection. The force–displacement curves are shown in Fig. 5. It is evident that the peak load increased significantly after local heat treatment, where the peak load of each test is shown in Fig. 6. Meanwhile, it can be observed from Fig. 5 that the failure displacements are

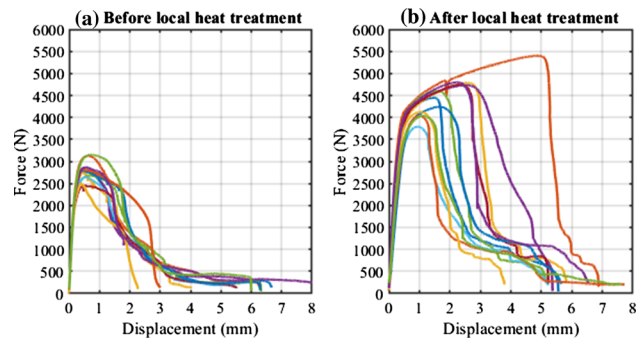


Fig. 5 Force–displacement curves of clinched joints

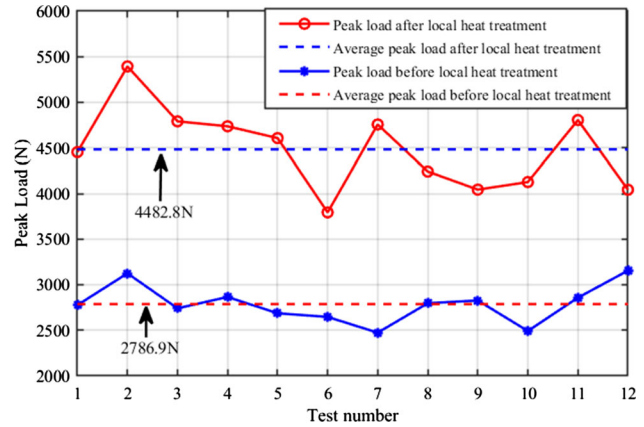


Fig. 6 Peak loads of tensile–shear tests

similar for clinched joints before and after local heat treatment. The energy absorption ability of joint can be directly seen from the area under the curve. Therefore, it is apparent that the energy absorption ability of clinched joints is enhanced after local heat treatment. That means automobile crash safety can be enhanced if the joining zone of clinched joints on the carbody is quenched.

Moreover, it can be observed from Fig. 6 that the peak loads of both groups of clinched joints are fluctuating, and the fluctuation for the quenching group is even more prominent. One distinct different data can be observed in Fig. 5(b), which is the second sample of clinched joints after local heat treatment. It can be observed from Fig. 6 that its peak load is close to 5500 N. Such apparent fluctuation is mainly because the local heat treatment process is not completely automatic and it is difficult to exactly control the heating temperature. In order to confirm the rationality of the experimental data, they are examined by the PauTa criterion (3σ criterion). The σ value can be calculated as follows:

$$\sigma = \pm \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n - 1}} \quad (\text{Eq 1})$$

where X_i is the i th peak load \bar{X} is the average load. The deviation of the load can be calculated as follows:

$$\Delta_i = |X_i - \bar{X}|. \quad (\text{Eq 2})$$

The examination results of the 3σ criterion are presented in Fig. 7. It can be seen that all of the test results satisfied the 3σ

criterion ($\Delta_i < 3\sigma$), which indicated that all data obtained from the tensile–shear tests are reliable. Therefore, twelve peak values were adopted to calculate the mean value for each group. The mean values are also presented in Fig. 6, which are 2786.9 and 4482.8 N. The tensile–shear strength of clinched joints increased by 60.85% after local heat treatment, which demonstrated the effectiveness of local heat treatment for enhancing the mechanical behavior of clinched joints.

3.1.2 Mechanism of Tensile–Shear Strength Deviation. The failure modes of clinched joints have been investigated by numerous scholars (Ref 18, 28, 29). It has been proved that the tensile–shear strength is mainly determined by two parameters: the neck thickness (t_N) and the undercut thickness (t_U), as shown in Fig. 8. t_N and t_U are related to the employed dies and joining parameters, which can be adjusted by optimizing clinching tools and punching forces. In this paper, these two parameters have been determined when we produce the specimen. Therefore, we have to modify other elements to increase the strength of clinched joint.

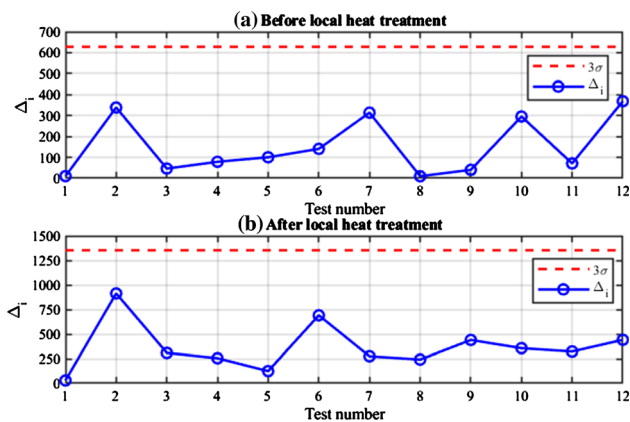


Fig. 7 3σ criterion examined results

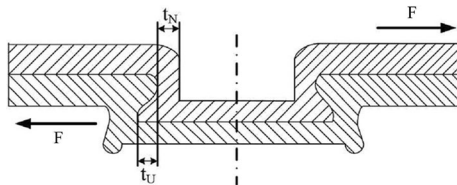


Fig. 8 Cross section of clinched joint

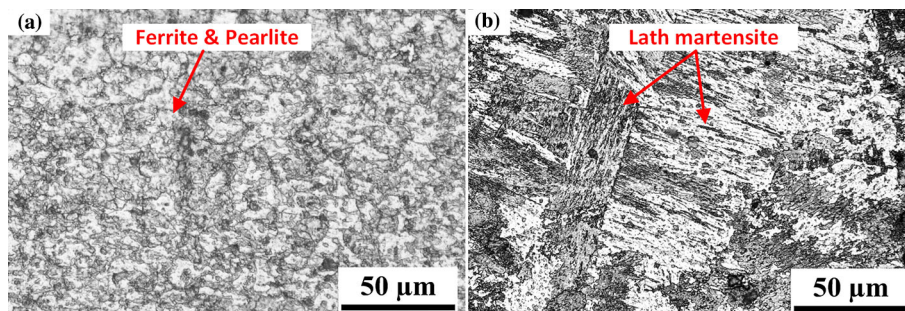


Fig. 9 Metallographic photograph of clinched joints in the undercut area: (a) before local heat treatment, (b) after local heat treatment

According to the failure modes of clinched joints in the static test, including bottom separation, hybrid bottom separation, neck fracture, and hybrid neck fracture (Ref 18), increasing the strength of substrates could enhance the strength of clinched joint. This suppose has been demonstrated by the tensile–shear tests in sect. 3.1.1. In order to better understand the mechanism of local heat treatment effect on mechanical property of clinched joints, we conducted metallographic analysis on the cross section of clinched joints through a metalloscope (CEICA DMI5000M). Besides, the microhardness of the clinched joint was measured after the metallographic tests to confirm the observed microstructure.

We have known that the content of carbon (C) in SPCC steel is 0.04% (Table 1), which indicates that it belongs to mild steel whose carbon content is below 0.25%. Mild steel presents low strength and hardness but high plasticity and toughness because it is mainly composed by ferrite and pearlite, which can be observed in Fig. 9(a). As referred earlier, increasing the strength of substrate can enhance the strength of clinched joint, so quenching was adopted as the local heat treatment process. The metallographic structure at the undercut area of clinched joint after local heat treatment is presented in Fig. 9(b), in which we can observe lath martensite. Compared with ferrite and pearlite, lath martensite is an ultra-strong microstructure because of solid solution and phase transformation strengthening.

Besides, the microhardness of the undercut area in the cross section of clinched joint before and after quenching was measured, which was 441.22 and 776.57 HV, respectively. It can be seen that quenching improved microhardness by 76.0%. The microhardness of clinched joints after local heat treatment can double confirm that the microstructure is martensite because it is over 516HV (Ref 30). Therefore, it can conclude that the local heat treatment improved the tensile–shear strength of clinched joints due to the ferrite and pearlite transformed into lath martensite.

3.1.3 Tensile–Shearing Failure Modes Analysis. In this subsection, the tensile–shearing failure modes of clinched joints before and after local heat treatment are analyzed. Firstly, the tensile–shearing failure modes of clinched joints before heat treatment are presented in Fig. 10. Most of the clinched joints before local heat treatment were failed in the mode of hybrid button separation, as shown in Fig. 10(b), and few of them were failed in the button separation mode as presented in Fig. 10(a).

However, it can be found that the main failure mode of clinched joints turned into hybrid neck fracture after local heat treatment, as shown in Fig. 11(a). Except hybrid neck fracture,

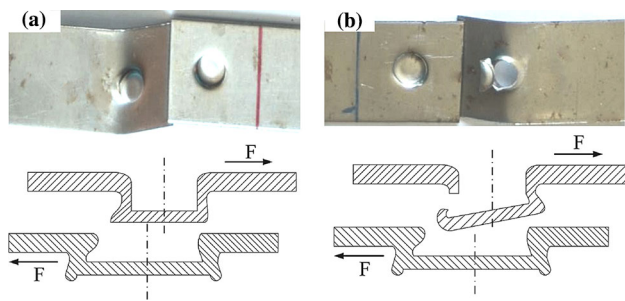


Fig. 10 Failure modes of clinched joints before local heat treatment in tensile–shear tests: (a) bottom separation mode; (b) hybrid bottom separation mode

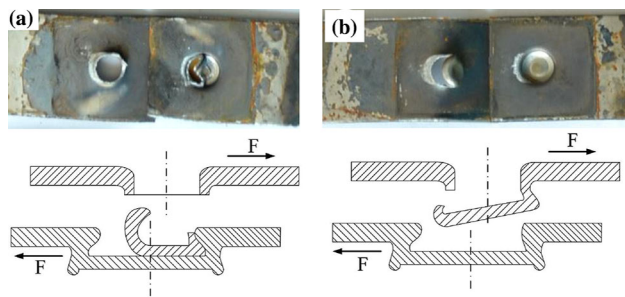


Fig. 11 Failure modes of clinched joints after local heat treatment in tensile–shear tests: (a) hybrid neck fracture mode; (b) hybrid bottom separation mode

others were failed in mode of hybrid bottom separation (Fig. 11b) which was same as the mode presented in Fig. 10(b).

Combining with the tensile–shearing results, it is evident that the clinched joint has superior tensile–shear strength when it is failed in hybrid neck fracture mode. According to the metallographic analysis, we can know that the main reason for the failure mode changing from hybrid bottom separation to hybrid neck fracture was the strength of substrate increased significantly after local heat treatment, and therefore, the same undercut thickness can bear a higher tensile–shear load. As a consequence, the neck fractured, but the bottom is not entirely separated. Finally, clinched joint was failed in hybrid neck fracture mode.

3.2 Fatigue Behaviors

3.2.1 Fatigue Life. The fatigue tests were conducted based on the average tensile–shear strength of clinched joints before and after local heat treatment obtained in sect. 3.1, which was 2786.9 and 4482.8 N, respectively. As mentioned in sect. 2.3, the fatigue life was tested under load levels of 90, 80, 75, 65, and 60% for the clinched joints before local heat treatment and 80, 70, 50, 37, 33, and 30% for the joints after local heat treatment. The fatigue failure mode of clinched joints before local heat treatment at the load level of 90% ($F = 2508.2$ N) was close to tensile–shearing failure since the fatigue life was quite low ($N \leq 300$); the clinched joints after local heat treatment at the load level of 80% ($F = 3586.2$ N) were in the similar scenario. Therefore, the fatigue results of clinched joints at these two load levels were neglected, and the retained fatigue data are presented in Fig. 12.

The fatigue load–fatigue life (F – N) curves for clinched joints before and after local heat treatment were fitted by the

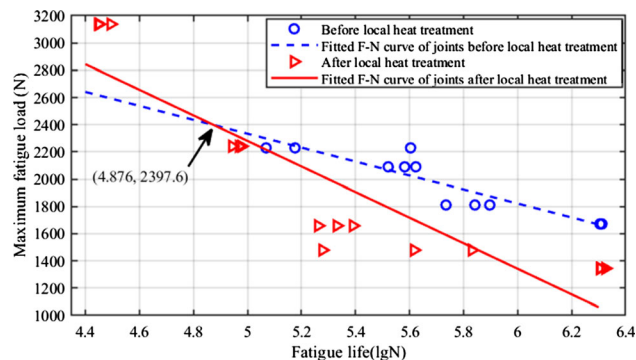


Fig. 12 F – N curves of clinched joints before and after local heat treatment

least square method based on the fatigue data, which are also presented in Fig. 12. The equations of the F – N curves for clinched joints before and after local heat treatment are $F = 4894.0 - 512.0\lg(N)$ and $F = 6975.0 - 938.8\lg(N)$, respectively. Based on these two equations, the crossover point of these two F – N curves can be solved, which is (4.876, 2397.6). It indicates that the fatigue performances are the same when the fatigue load is at 2397.6 N for these two kinds of clinched joints. Nevertheless, the fatigue behavior of the clinched joint after local heat treatment is better than the joint before local heat treatment when the fatigue load is over 2397.6 N. Yet the clinched joint before local heat treatment has superior fatigue life if the fatigue load were below 2397.6 N. Therefore, we can conclude that local heat treatment can improve the fatigue endurance of clinched joints for high-fatigue loads. Besides, the fatigue endurances of clinched joints under low load levels are also excellent even it was shortened after local heat treatment.

The typical fatigue failure modes of clinched joints before and after local heat treatment are presented in Fig. 13 and 14, respectively. It can be seen that fatigue failure modes include hybrid bottom separation, hybrid neck fracture, and substrate fracture.

Particularly, as can be seen from Fig. 13(a) and 14(a), the fatigue failure mode of clinched joints is similar to tensile–shear failure modes when the load levels were 90% (2508.2 N) and 80% (3586.2 N), respectively, for clinched joints before and after local heat treatment. Such results were reasonable because their fatigue life was very short which was below 300 cycles.

The fatigue failure modes of clinched joints before heat treatment were bottom separation (Fig. 13b) and hybrid neck fracture (Fig. 13c) when the load level was at 75% (2090.2 N) and 80% (2229.5 N), respectively. It is worth highlighting that the bottom separation resulted from fatigue was along with a fracture on the lower substrate, as shown in Fig. 13(b). In addition, as can be seen in Fig. 13(d), the substrate was divulsive when the fatigue load level was at 65% (1811.5 N), which is denoted as substrate fracture mode. The fatigue tests were artificially stopped if the fatigue life of the tested joint was over two million, which case happened when the fatigue load level was at 60% (1672.1 N) for clinched joints before local heat treatment.

For the clinched joint after local heat treatment, the hybrid neck fracture was the main fatigue failure mode when the load level was below 80%. Specifically, the fatigue failure mode is shown in Fig. 14(b) when the load level was 70% (3138 N) and

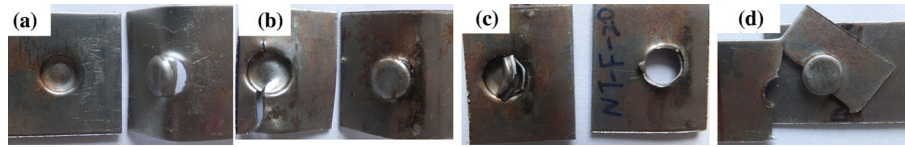


Fig. 13 Fatigue failure modes of clinched joints before local heat treatment



Fig. 14 Fatigue failure modes of clinched joints after local heat treatment

50% (2241.4 N), which was also similar to the tensile–shear failure mode. However, the hybrid neck fracture was combined with upper substrate division when the fatigue load levels were 37% (1658.6 N) and 33% (1479.3 N), as shown in Fig. 14(c). The fatigue test was ceased artificially when the load level was 30% (1344.8 N) as the fatigue cycle was over two million.

Based on the previous analysis, it can be seen that the fatigue performance of clinched joint is mainly determined by the quality of the joint when a relatively high level fatigue load is applied to it. However, when a low fatigue load is used, the performance of the jointed materials become significant to the fatigue behavior of clinched joint. In short, local heat treatment is very useful to increase clinched joints' statics and fatigue performances when the joint is working under high load condition.

3.2.2 Fatigue Failure Mechanism. In this subsection, the fracture surfaces of typical fatigue failure modes occurred in the fatigue test are examined by using a scanning electron microscope (SEM, TESCAN: VEGA3 SCAN) to investigate the failure mechanism of the tested joints. The fatigue failure mechanism has been investigated by plenty of researchers, such as the results presented in Ref 13, 15, 28, 29, 31. This paper demonstrated that fretting wear is one of the main reasons for fatigue failure of clinched joints (Ref 31). The typical fatigue failure modes are analyzed in sect. 3.2.1. The fretting wear-occurred area is shown in Fig. 15, where position A is the contact area of the lap joint and position B is the neck of the clinched joint. Therefore, SEM analysis was focused on the fretting wear area to investigate the fatigue failure mechanism of clinched joints before and after local heat treatment.

The typical fatigue failure modes of the tested clinched joints were randomly selected to conduct fracture analysis via SEM. According to the discussion in sect. 3.2.1, the typical fatigue failure modes of clinched joints before local heat treatment include hybrid neck fracture and substrate fracture, as shown in Fig. 13(c) and (d), respectively. Besides, the bottom separation mode, which is shown in Fig. 13(a) and (b), has no fracture. For the clinched joints after local heat treatment, the typical fatigue failure mode is hybrid neck fracture, as shown in Fig. 14. The referred fatigue failure modes with fractures were examined by SEM.

Figure 16 shows the SEM images of clinched joint before local heat treatment in the failure mode of hybrid neck fracture. The black matte can be observed on the substrate where the area is corresponding to the position B in Fig. 15, which was

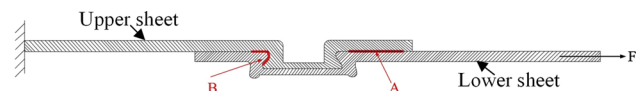


Fig. 15 Schematic of fretting wear position in the clinched joint

resulted by the fretting wear during the fatigue test. Particularly, the black matte was resulted from abrasive dust which is produced by the peeled-off material when the surface material moved back and forth at position B. Therefore, the fracture closing to the fretting wear area was scanned by SEM, as shown in Fig. 16(a) and (b). The presented images are the fracture surface magnified 1000 times. The cleavage steps can be observed in Fig. 16(a) and (b), which indicated that the source of crack was in this zone which is at the fretting wear area (position B in Fig. 15). In addition, as can be seen in Fig. 16(c) and (d), the wide fatigue striation can be observed, which was resulted from quick crack propagation under high stress amplitude. That is to say a crack originated at area (a) and (b) due to the fretting wear and quickly propagated to area (c) and (d). Consequently, the neck of the clinched joint was fractured.

The SEM images of clinched joint failed in the mode of substrate fracture are presented in Fig. 17. Firstly, similar to neck fracture failure mode, we can also observe black matte on the surface which is corresponding to the position A in Fig. 15. Secondly, fatigue striation with features of cleavage steps can be observed in Fig. 17(a) and (b), which indicated that the fracture was originated from this zone. Moreover, the dimples can be found in Fig. 17(c) and (d). The shape of the dimple revealed that the substrate was under normal stress when the crack propagated to this area. In other words, the crack source was at area (a) and quickly propagated to area (c) under the fatigue load.

Last but not least, Fig. 18 shows the SEM images of clinched joints after local heat treatment under the load level of 33% (1479.3 N), which is the most typical fatigue failure mode. From Fig. 18, we can observe the cleavage surface and second cracks in all of the four SEM images. Moreover, it is evident that the fracture mode of clinched joint after local heat treatment is transcrySTALLINE rupture, which could result from the increase in brittleness of the connected sheets. That means the speed of the crack propagation increased when the clinched joint after local heat treatment. Consequently, the fatigue endurance was shortened when the clinched joint was in the

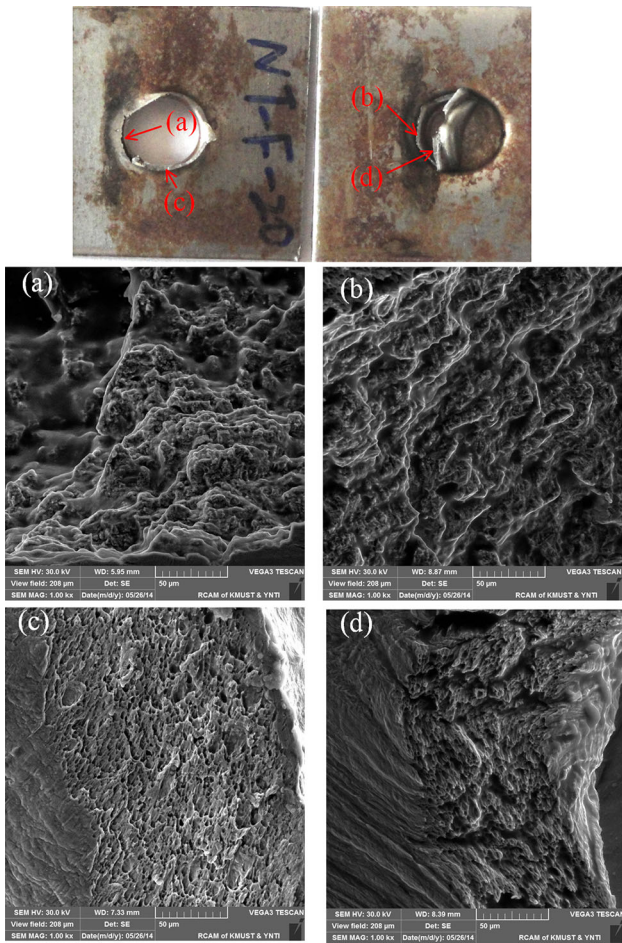


Fig. 16 SEM images of clinched joint before local heat treatment at a load level of 80%

circumstance of low load level. However, it is worth noting that the fatigue behaviors of clinched joints working under high load levels are enhanced.

Based on the fracture analysis and fatigue test results, we can draw the conclusion that local heat treatment improved the overall mechanical property of clinched joints, since it overcame the main deficiency of low tensile–shear strength of clinched joints and enhanced the fatigue behavior of clinched joints working under high load circumstance.

4. Discussion

In this paper, a local heat treatment method was proposed as a post-process to increase the mechanical performance of clinched joint in SPCC steel. Tensile–shearing and fatigue tests were conducted on clinched joints with and without local heat treatment. The tensile–shearing results indicated that local heat treatment was an effective method to enhance the static behavior of clinched joints in SPCC steel. Specifically, its static tensile–shear strength increased by 60.85% after local heat treatment. The metallographic analysis demonstrated that clinched joints’ strength increase was due to the microstructure of undercut area changed from ferrite and pearlite to lath martensite.

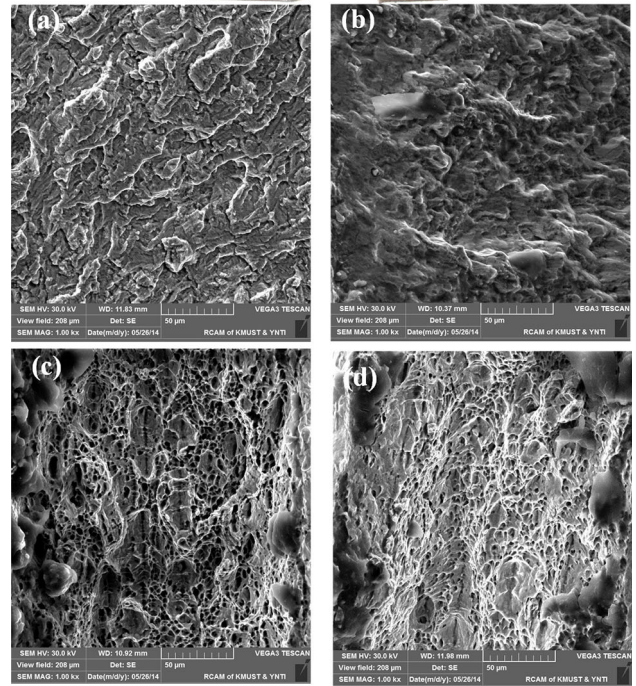
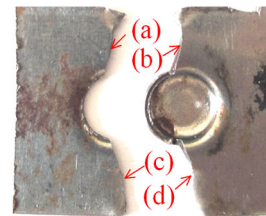


Fig. 17 SEM images of clinched joint before local heat treatment at a load level of 65%

The fatigue tests have shown that local heat treatment could increase the fatigue endurance when the maximum fatigue load was over 2397.6 N. The fatigue fracture analysis via SEM revealed that the fatigue failure process of clinched joints started from fatigue crack of which was resulted from fretting wear. On the other hand, it also found that the local heat treatment would shorten the fatigue life of clinched joints when it was under low fatigue load level as the fracture mode became transcrystalline rupture. However, although the fatigue life of clinched joints after local heat treatment was shortened under low fatigue load, the fatigue performance of clinched joints was still excellent compared with other joints. So we can conclude that local heat treatment is a promise approach to grow in comprehensive behaviors of clinched joints.

5. Conclusions

Based on the experimental results, we can conclude that local heat treatment is effective to improve the overall mechanical performances of clinched joints in SPCC steel. This study was performed as a primary investigation on conducting proper post-process to improve clinched joints’ mechanical performances. The effectiveness of post-process has been verified which can be extended to clinched joints in other materials according to the behavior of jointed sheets.

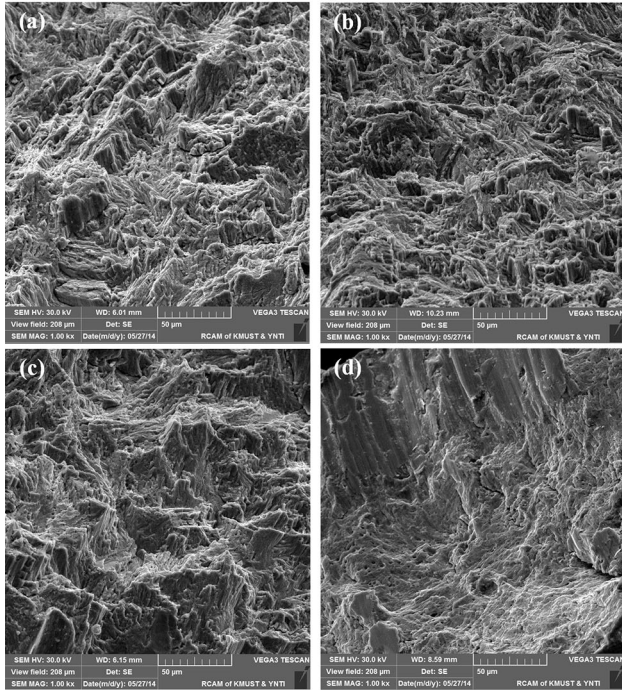
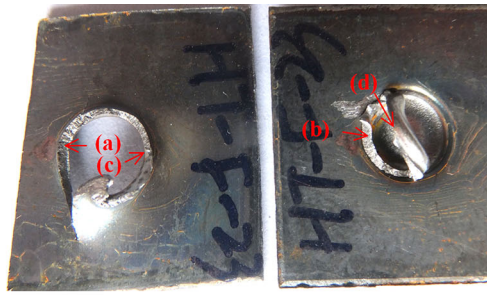


Fig. 18 SEM images of clinched joint after local heat treatment at a load level of 33%

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