1. Introduction

Clinching techniques have been more and more used in different industrial areas, especially in automotive industry, since the last ten years. This technique can join two or more sheets of same metallic materials as well as of different ones or even a sheet of metal with a sheet of non-metal by cold forming. Another advantage of this joining technique is that usually it doesn’t need additional heat input or additional joining parts. Therefore this technique is considered to be ecologically friendly, economical and will have a higher and higher application potential. It is an alternative joining technique to the traditional spot welding in many manufacturing areas.

A clinched joint is a form and force fitted joint. The proportion of the force and form fit depends on the type of joining element, the material to be joined and the applied conditions. Similar to other joining techniques, the quality of clinching joints is always essential, and therefore, a suitable in-process monitoring method will be very important for the application of clinching techniques in volume production.

2. State of the Clinching

A typical clinching process without cutting is schematically shown in Fig. 1. The metal sheets are put in a set of tools and the joint is formed only under pressure. The process in detail will be mentioned later.

The quality of a clinching joint can be evaluated by different parameters, for example, static and fatigue strength of the joint, corrosion resistance of the joint or visual appearance of the joint. Common applications demand that the quality of joints is quantified through the ability to sustain the design load in the structure under normal service conditions without causing a failure. Mechanical testing is often used to assess the joint quality by destructive testing of specimens or relevant structures. Obviously, destructive testing is not acceptable for routine production monitoring because it is expensive, complicate to undertake, difficult to...
interpret, and is affected by many factors associated with the joining process. As a result, a range of non-destructive testing methods has been developed for clinching. These destructive methods normally cannot measure joint qualities directly, rather, they infer the joint quality from one or more parameters measured during the joining process. These values are compared with references which were obtained in advance by destructive testing. In this way, the joint quality can be predicted and evaluated. Generally, a clinching joint is characterised by specific quality-features illustrated in Fig. 2. These quality-features depend on clinching processes, clinching tools, process parameters and the material to be joined.

It can be seen from Fig. 2 that these two quality-features, the neck thickness and the under cut, cannot be directly measured without destroying the joint. Their characteristics can only be revealed by using the micrographic examination of the cross section of the joint. The other two quality-features, the bottom thickness and the die depth however, can be easily measured, and therefore, the bottom thickness is often used as an evaluating parameter of the joint quality in real applications.

Although a direct measurement of the bottom thickness provides a good quality indication, this method is not suitable in volume and automatic production because it needs a lot of manual measurement which may introduce errors and in some cases this manual measurement is impossible. To obtain a reliable quality assessment of the joint quality, different monitoring methods have been developed and employed in the last several years.

3. Process Monitoring of Clinching

A reasonable monitoring method is during a joining process by measuring actual process parameters, e.g. the setting force and the punch displacement, to realise process monitoring. This method is based on that the setting force reflects the deformation force on the material, and the punch displacement indicates the geometric change of the sheets during joining process.

The data of the setting force and the punch displacement is acquired through a monitoring system with a computer, interfaces and sensors. The system is equipped with a force sensor and a position sensor, which sends the information about the joining process to the measuring computer. The computer is then used to sample, save the measured data, to generate necessary responses, curves and documents etc.

The usually used monitoring methods at present are window monitoring and tolerance monitoring. The window monitoring method sets different windows in advance inside the measurement computer, which correspond to the force-displacement-diagram areas. If these windows are not injured by an on-line detected curve during the joining, this indicates that the joint quality is acceptable; otherwise the joint quality is poor. On the other hand, the tolerance monitoring method creates a reference curve and its corresponding upper and lower limit curves in advance. During application if an on-line detected curve goes out of the limits, the clinched joint will have unacceptable quality.

This paper describes an investigation of using window monitoring in clinching process under various applying conditions.

4. Experimental Equipment and Process

As monitoring system an apparatus named Digiforce 9306 was used in this study. Eckold R-DF8 was employed as clinching machine. The materials tested were Steels DC 04 with thickness of 0.8, 1.0 and 1.15 mm as well as H 340 with thickness 1.0 mm. Their mechanical properties are listed in Table 1.

The complete monitoring system is schematically shown in Fig. 3. A strain gauge is used as a force sensor and attached on the C-frame of the clinching machine by adhesives. A slide potentiometer sensor is used as a position sensor which is mounted between the punch and the die of the clinching machine, to measure the punch displacement. Both signals obtained from sensors are amplified and then transferred to a monitoring system which measures, processes and saves the signals. The monitoring system can communicate with a personal computer to achieve more functions.

The adjustable stop piece, in Fig. 3, controls the movement range of the hydraulic cylinder, and thus to control the
maximal punch displacement or the bottom thickness of a joint. When the stop piece is adjusted upwards, the distance which the punch can move downwards will be smaller, so the maximal punch displacement will be limited. During a clinching process, when the movement of the punch reaches the stop piece, the punch will move backwards and the hydraulic system will be stopped. The machine will be released and a joint will be formed.

5. Results and Discussion

5.1. Reference Curve

The first step of the monitoring process is to establish a reference curve under standard conditions. In this study the standard conditions were determined after a range of experiments as below: the material of both sheets was steel DC 04 in thickness of 1.0 mm; A set of tools was selected with the punch 714.501 126 and the die 787.10; the stop piece was adjusted to such a position that the bottom thickness of a joint was 0.55 mm and the corresponding maximal setting force was about 34 kN by monitoring system. Under these conditions a clinched joint would be supposed to be of good quality. The relevant monitoring curve, named force-displacement-curve, was considered as the reference curve, shown in Fig. 4.

The formation of the force-displacement-curve can be explained in brief with refer of Figs. 1 and 4. The curve can be divided into three phases, from start to first bending point is as phase one, from first bending point to second bending point as phase two and the rest as phase three. In phase one the metal sheets are put on the laminas of die; the hydraulic system starts; the punch system moves down; first the hold down piece contacts the upper sheet, to fix the sheets between the punch and the die; then the punch reaches the sheet, starting the pressing process. The punch presses the sheets and they move downwards together, whereas the curve moves upward. This process continues to the first bending point, at this point the lower sheet reaches the die anvil and the sheets can not move downward any more. Under continuous pressure part of sheets flows around outside to occupy the free space inside the laminas which moves little outside and the punch continues pressing downward. Obviously, these actions need more deformation force. This is why the first bending point occurs and in phase two the slope of the curve is greater than in phase one. The reason of the second bending point is that at this point the free place is nearly filled because of the spring's limiting on the laminas. During phase three the distance piece of punch system will also reach the sheets, to forge the whole joining area. Therefore it needs much greater deformation force and the curve rises in the biggest slope. When the punch system reaches the stop piece, the punch maximal displacement and maximal setting force occur in the curve. With the return of the punch, the curve moves downward in a certain slope because of the stiffness of the clinching machine. When the force curve reaches zero, the clinching machine can be considered to be released. The punch system moves upward to the original position and a clinching process is finished.

In this experiment for the monitoring system 5 windows, W1 to W5, are established depending on the features of the reference curve. The size of each window is determined together according to pre-tests under different clinching conditions. These sizes of windows are dependent on the tolerant range of the reference curve under the same condition and other actual curves under different conditions which may occur in production. If a size of a window is too big, it could happen that a wrong curve, which is from a not expected clinch process under another condition, goes into the same area of the reference curve and will be evaluated as good one. On the other hand, because of fluctuations a
curve nearly like reference curve could be considered as bad one, if a size of the window is set too small. To obtain proper size of each window, it is therefore necessary, that possible quality problems met during clinching will be previously analysed and then their corresponding pre-tests will be carried out under these conditions to find out suitable size for each window.

For this study W1 (0.20 mm long × 3.97 kN broad) is set at the start point of the curve, W2 (0.30 mm long × 2.10 kN broad) and W3 (0.16 mm×4.0 kN) at the first and the second bending point, W4 (0.15 mm×3.5 kN) at the point of maximal setting force and W5 (0.21 mm×3.0 kN) at the point where the setting force is zero during the returning of the punch. The in and out directions for curve through the windows are designed as follows: for W1 and W3 the curve should thread them from left side to right side; for W2 the curve should go in from left and out from the top of the window; W4 in from bottom and out from bottom, W5 in from top and out from left. In the real monitoring applications, if a measured curve goes through these set windows in the above designed procedure, the quality of the joint will be considered to be good and a mark “OK” will be indicated in the monitoring system. If a curve goes through the windows above in any other ways, some of the windows will be considered as injured and the quality of the relevant joint may not be as good as defined. In this case the system sends out a “NOK” signal.

It has been tested and proved that under the same experimental conditions, if the monitoring curves were nearly the same, the clinched joints would have similar good quality. In these cases the monitoring system indicated that the windows were not injured and an “OK” signal. Under changed conditions the monitoring results are discussed in details as follows.

5.2. Change of the Metal Sheet Thickness

The sheet thickness was changed from 1.0 mm to 0.8 mm or 1.15 mm to get different thickness combinations of sheets. Their monitoring curves changed consequently, as shown in Fig. 5(a). It can be seen from the figure that the force–displacement-curves have injured some monitoring windows except for the reference curve.

For the combination with 1.15 mm sheets, because of its greater thickness, the punch reached the upper surface of the sheets earlier than that with the 1.0 mm sheets. Therefore the start point of the force–displacement-curve occurred earlier and whole curve moved towards left, and the windows W1 to W3 were injured. Its maximal setting force was higher than that under the standard conditions, because the stop piece for these three tests was kept constant. Fig. 5(a) shows that the maximum force is about 44.5 kN and is over the window W4. The curve doesn’t reach W5. On the contrary, for the combination sheets in 0.8 mm, because of its smaller thickness, the curve doesn’t reach windows W1 and W4, and injures windows W2, W3 and W5. In the case the curve shifts to right and the maximum force is about 25 kN.

Their metallographic pictures of the cross sections from these joints are shown in Fig. 5(b). Although these joints have nearly the same microstructure, their bottom thicknesses are different. As previously mentioned, the bottom thickness is an important evaluating parameter for a clinched joint. Therefore, with the change of the sheet thickness from 1.0 mm to 0.8 mm or to 1.15 mm, the monitoring system could distinguish these changes and point out that the corresponding joint quality could be changed from standard conditions and would be evaluated as unacceptable (NOK), because some monitoring windows were injured.

5.3. Change of Sheet Materials

In this test another type of steel, H 340 in 1.0 mm thick, was used as the metal sheet clinched. It can be seen, from Table 1 mentioned above, that in the same thickness, H 340 has a higher yield strength and tensile strength than DC 04. It means that H 340 needs greater pressure to obtain the same deformation for clinching than DC 04 does. Figure 6(a) shows the force–displacement-curves from H 340 and DC 04. Because the thickness of both materials is the same, their curves start at the same position. During the joining process the curve of H 340 is higher than that of DC 04. Its maximum setting force is 37.5 kN. In Fig. 6(a) windows W1 and W5 are not injured, but W4 is injured; the curve goes over windows W2 and W3. Therefore a “NOK” signal is sent out, i.e. the joint quality of H 340 is not expected. Figure 6(b) shows the metallographic pictures of the cross sections for these tests. These two joints have different values of the bottom thickness. Although the microstructure of joint from H340 seems not bad, the joint would be evaluated as NOK because of its deviating curve under changed material condition.
5.4. Change of the Punch Type

In clinching process the punch type has great effects on the quality of joints. Incorrect selection of a punch may cause joints with poor quality. Three types of punches, punch 714.501 120, 714.501 126 (standard) and 714.461 148, were employed here to investigate their effects in the monitoring process. Figure 7 is a schematic diagram of the punch geometry. A punch consists of two parts, a punch piece and a distance piece. The difference among three tested punches is their diameter and their free length. If the free length of a punch is longer, the length of the distance piece will be shorter, because the distance from top to bottom of the punch piece is constant.

In the test metal sheets were DC 04 with 1.0 mm thickness. The clinching conditions kept the same like in the reference curve and the only parameter changed was the type of punch. Their monitoring curves are shown in Fig. 8(a). For punch 714.501 120, because of its shortest free length, its distance piece will reach the upper sheet earlier than the other punches during clinching process, this causes higher deformation pressure. Therefore its force–displacement-curve is much higher than that of the other two punches. Its setting force reaches a value of 45 kN. Because the maximum measuring force of the monitoring system was preset to 45 kN, the actual force in this case is higher than the measure range and the curve becomes a flat line in the curve.

In the case by using punch 714.461 148, the curve moves a little downwards because of its smaller punch diameter. For this punch, its 4.8 mm free length is longer than 3.0 mm (the sum of sheet thickness plus the depth of die), so the distance piece of the punch will not reach the upper sheet during the clinching process. Hence there is no forging action from the distance piece for the joint and its deformation is only caused by the punch piece. Therefore its maximal setting force is only 23 kN and the curve rises up much slowly. The monitoring system shows that the window W1 is not injured by either of three curves, but W2 is injured by the curve from punch 714.461 148. For W3 to W5 the curves except for the reference one are out of the quality allowance.

From Fig. 8(b) it can be seen that the metallographic pictures of the cross sections from these tests. The joints except for the joint produced with the standard punch have poor microstructure. Their mechanical properties tests proved also the same results. The average tensile force of the joint with standard punch reached 2.85 kN, while the average tensile force of the joint with punch 714.501 120
were 2.52 kN as well as with punch 714.461 148 only 1.76 kN. In fact, these two kinds of joints were evaluated as NOK according to their monitoring curves.

5.5. Change of the Die Type

Three types of dies with different depth, die 787.08, 787.10 (standard) and 787.12, were introduced in the tests. Geometry of a die is schematically showed in Fig. 9. When using die 787.12, the pressing distance from the contact point between the punch piece and the upper sheet to the die anvil is 0.2 mm longer than that when using die 787.10, and 0.4 mm longer than that when using die 787.08. Just like above tests, here the experimental conditions except for the die were kept the same as the standard conditions.

It can be seen, from the monitoring curves in Fig. 10(a), that the curve from using die 787.12 has the longest pressing phase and extends to the right side of window W2. This curve doesn’t injure windows W1, W4 and W5. On the other hand, the curve from die 787.08 has the shortest pressing phase. The curve is in windows W1 and W2 in order, but not in other windows. Therefore, change of die types can also be detected by the window monitoring system.

Figure 10(b) presents their corresponding metallographic pictures from these tests. The microstructure of these joints appears without great difference except for the little gap in the joint with die 787.08, but their mechanical properties tests showed a standard deviation of about 10 percent. The average tensile force of the joint with standard die reached 2.85 kN, but the average tensile force of the joint with die 787.08 were 2.53 kN and with die 787.12 about 2.58 kN.

5.6. Change of the Bottom Thickness

The change of bottom thickness is realised by adjusting the position of the stop piece in the punch moving system, which controls the distance of punch movement. The shorter this distance, the greater the bottom thickness of a joint will be. Clearly, the change in the position of the stop piece could directly affect the joint quality, which can be identified by the monitoring system.

Three different positions of the stop piece were selected in the tests, in which joints with bottom thickness of 0.49, 0.55 and 0.72 mm were correspondingly produced. The force-displacement-curves are showed in Fig. 11(a). Because all other joining conditions were kept constant for these three tests, their growing part of the curves had a similar form. The difference is their maximum forces. In these cases the monitoring system can also monitor the joining process by properly detecting the maximal force. In Fig. 11(a) the curve with bottom thickness of 0.49 mm injures W4, the curve with bottom thickness of 0.72 mm does not reach W4 and W5 due to its low deformation. Thus the monitoring system can also detect whether a joint has an expected quality or not, when the bottom thickness is
changed. Fig. 11(b) shows these three metallographic pictures of the cross sections. Except for the difference in the under cut, their microstructures illustrated nearly identical shape. Although the average tensile force of the joint with bottom thickness 0.49 mm reached 2.86 kN in a similar amount of the value with the standard joint (2.85 kN), this kind of joints would not be recommended in use because of its great setting force. The greater the setting force, the more heavily loaded the joining system. For the joint with bottom thickness 0.72 mm its average tensile force equalled 2.45 kN and had about 15 percent decrease in the value compared with the standard joint.

6. Conclusions

Comparing with the tolerance monitoring method the window monitoring method needs less time for evaluating, because it analyses only parts of curve data which are related to windows, but in tolerance monitoring method nearly whole curve data will be analysed. Another feature is that it is possible to analyse and to identify concrete causes of condition changes based on windows injured in production. This is a distinguish advantage with this monitoring method. In the tolerance monitoring method errors can be only ordered as two types: upper error or lower error, which correspond upper or lower error curve exceeded. In the window monitoring method there is more information about a monitoring situation, to distinguish which errors or changes occur possibly according to windows injured during a clinch joining, because every window offers its monitoring messages.

The process monitoring method with window technique used in this study is capable of applying actions to usual clinching process. It can reliably recognise the change of setting conditions during clinching processes so that an assurance for repeatable joint quality can be achieved. This capability is very useful in industrial volume production, because setting conditions for a monitored joining of products are fixed usually, any change of them in the production maybe cause changes of the joint quality. By using such a monitoring system the quality of joints can be evaluated on line to prevent products with poor quality from entering into further production steps or from reaching to customers.

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