Journal of Manufacturing Processes 34 (2018) 650–658

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Development of a hot stamping clinching tool

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ARTICLE INFO

Keywords:
Clinching
Hot stamping
Resistance heating

ABSTRACT

A hot stamping clinching tool that integrates a forming system, a heating system and a cooling system is developed. A traditional heating furnace is replaced by resistance heating technology. DEFORM-3D is used to simulate the heating process, cooling efficiency and formability in the design stage. A series of experiments confirms the design of the tool. Results show that the tool structure accurately controls the movement of the electrode and the punch stroke. Experiments showed that the condition of the sheet's surface, the sheet's thickness and its size affect the resistance heating. If the contact surface between sheets is uneven, current flows through from the partial contact point, which results in non-uniform heating. If two layers of sheets of different thickness are heated at the same time, the thinner the sheet, the faster is the heating rate. An increase in the sheet's size results in a decrease in the heating rate. In terms of the connection strength, due to the high cooling rate in the present experimental, the tensile strength of the sheet at the clinching point is increased by 3 to 4 times. Resultant the elongation is reduced to less than 2% so the cracking point occurs around the clinching joint and not the joint point itself, during shear strength test. Therefore, it is important to control the cooling process to get better clinching joint condition.

1. Introduction

In recent years, the vehicle industry has grown rapidly. Regulations related to the environment and energy consumption that are set by Europe and the U.S. demand higher standards. CO_2 reduction and environmental protection are important for the vehicle industry. The global automotive industry has had to reduce energy consumption to protect the environment. Reducing a vehicle's weight is an efficient method to achieve this target. A study by Han and Clark [1] showed that a 57 kg weight reduction in an automobile results in an increase in fuel-economy of 0.09–0.21 km/L. To reduce the weight of automobiles, ultra-high strength steels with high specific strength have been widely used for the body-in-white in the past few years [2]. The sheet parts are often joined by spot welding. However, spot welding machines are costly and have high energy consumption. For ultra-high strength steels, cracks can also be initiated and propagated in the spot welding area [3]. The mechanical clinching process is an alternative to spot welding for the joining of ultra-high strength steels. The mechanical clinching process is a single step mechanical joining method that combines materials that have no additional complementary joining elements (e.g., screws, rivets). This further reduces the weight of the body-in-white.

The mechanical clinching process uses a punch and a die to enable the local formation of sheets at cold temperatures and then the jointing of the sheets together. Clinching was first used by the German company, TOX, in the 1980 s [4]. Clinching is a mechanical fastening method that joins sheet metal without the need for additional components. The sheets are formed by a punch and die to generate the interlock between the lower and the upper sheets. The connection strength of the clinched joint for the sheets depends on the value of the interlock and the resulting neck thickness in the sheet at the punch side [5]. The clinching process allows excellent tightness, resistance to corrosion, a simple machining route and high connecting strength. It also allows sheets of different materials to be connected with low noise pollution and low cost. Many studies of the mechanical clinching process have tried to determine the joint strength [6]. A review paper on advancement of the FEA of clinched joints was pulished by He [7]. The author reviewed different works related to process, strength, and vibration characteristics of the clinched joints. Lee et al. [8] used finite element software to analyze the neck thickness and interlock, using the bottom thickness of the die to simulate the connection failure value. The simulation was also compared with an actual experiment to verify the reliability of the software. Y. Abe et al. [9] modified the diameter and shape of a die that was used to join high strength steel sheets and aluminium alloy sheets. The neck thickness and interlock were measured by experiment. The failure mode and fracture phenomena were also observed. De Paula

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https://doi.org/10.1016/j.jmapro.2018.06.022
Received 21 November 2017; Received in revised form 5 June 2018; Accepted 12 June 2018

et al. [10] used a simulation model to modify the detailed geometry for a die and found that the neck thickness depends on the interlock. Mucha and Witkowski [11] experimented with different clinching methods, such as single-point and multi-point, to determine the connection strength. The results show that the connection strength is greater when parallel multi-point is used and this method gives a stronger join than single-point connection.

The results of these studies show the advantages of mechanical clinching. This joining process has been widely used in the automobile, building and electrical industries in recent years [12–14]. However, the mechanical connection strength is less than that which is achieved using traditional spot welding. The mechanical clinching of ultra-high strength steel sheets is also difficult because ultra-high strength steel sheets have low ductility, so fractures can occur in the joint area. In order to avoid this defect and improve the joint strength for the clinching of ultra-high strength steel sheets, hot stamping technology is used for the clinching process. Chen et al. [15] improved the joint strength of mechanical clinching by using hot stamping technology. The results show that the interlock value is 15% greater than the value when there is no heating process. The neck thickness is 5% less than the value for cold stamping clinching. The static strength of the joined sheets is 27% greater than that for cold stamping clinching. The preheating process also increases the ability of the material to flow. The stamping load decreases by 77%, to cold clinching process.

The abovementioned results proved that hot stamping clinching is an efficiency way to join steel sheets. However, the manufacture process of the hot stamping contains heating the sheet up to austenitization temperature and maintaining this temperature for a period to ensure the homogenization of austenite structure. The sheet is then quenched within the die at a cooling rate that is greater than 30℃/s and the austenitic microstructure transforms into martensite with ultra-high strength parts [16]. Compared to traditional cold clinching, the number of production processes and the cycle time are increased and the equipment is more costly. Most of the sheet parts that are to be connected are also large and complex so they cannot be sent to a furnace for the heating process. Therefore, traditional hot stamping process is unrealistic to combine clinching process to joint general sheets. A new tool is need to complete this task.

This study designs and develops a tool that allows the hot stamping process and the clinching process to be performed inside a single tool, to simplify the process. The resistance heating system and the cooling system are designed first. Deform 3D software is used to simulate the cooling and heating efficiency. The stamping die for a hot stamping process is then developed. Finally, the formability of the sheet, the static strength of the joints and metallographic analysis are used to portray the advantages of this process.

2. Research methods

To allow hot stamping clinching for more jointing applications that are not limited by sheet size or shape, a hot stamping clinching tool was designed. This design incorporates heating, forming and cooling systems. The complete construction is shown in Fig. 1. Each system and its design are introduced in the following sections.

2.1. Heating system design

Local resistance heating was used to heat the sheet during the hot stamping clinching process. A schematic diagram of the resistance heating system is shown in Fig. 2. Resistance heating is a process whereby thermal energy is produced by passing an electrical current through a specifically designed conductor. In this application, resistance heating involves the direct passage of current through the sheet to produce heat. When the electric current passes through the conductor, the conductor blocks the current flow and the loss of power is converted to heat energy [17]. The heating system uses a circuit that is composed of control power input modules, transformers, copper wire and conductive copper. The winding ratio for the transformer is 4:1. The transformer converts a high voltage and low current input to a low voltage and high current output that heats the sheet. The hot stamping die is placed between two electrodes. When the central area of the test sheet is heated to 900℃, the forming and cooling process begins. In order to avoid dangers such as short circuits, electric shocks or leakage, direct electric resistance heating is used. This uses pairs of electrodes on the vertical clamping plates, which form circuits, and generates a low voltage and high current flow from the transformer output side to heat the higher electrical resistance sheet panel.

After the initial design of the heating system, finite elements analysis software DEFORM-3D is used to simulate resistive heating, in order to confirm the reliability of the design. The layout of the electrodes and test sheets for the resistance heating system is shown in Fig. 3. This consists of an upper sheet, a lower sheet and electrodes (anode on the right and cathode on the left). The simulation parameters for the resistance heating model are shown in Table 1. The initial design of electrode is cylindrical and the material for the test sheet is CSC-15B22, which is manufactured by the China Steel Corporation. The relative permeability, resistivity, thermal conductivity and specific heat capacity are the required material parameters for the simulation and the data is shown in Table 2.

2.2. Cooling system design

In order to provide rapid cooling for the heated sheets, to form a martensite structure from an austenitic structure, cooling channels are required inside the punch and die. An air-cooled chiller was used to provide 15℃ cooling water that passes through the cooling channel. The cooling channel in the binder, the lower die and the electrode uses another design. A schematic diagram of the cooling channel design is shown in Fig. 4. There is a circular channel that is 5 mm wide and 22 mm deep inside the binder. The inlet and outlet for the cooling channel are on the same axis line. For the lower die, the cooling channel is a simple ø5 mm through hole. During the heating process, the electrode can generate heat by itself. In order to prevent the heat from destroying the insulated bushings, an ø6 mm cooling channel passes through the electrode to remove the heat.

2.3. Forming system design

After the hot stamping clinching process, the connection strength of sheets depends on the neck thickness (t_n) and the interlock value (f), as shown in Fig. 5. The best neck thickness is between 1/3 and 2/3 of the thickness of the upper sheet [18]. The shape of the upper and lower die takes this into account. In this study, the lower die and the punch design are based on those for previous studies in the same research laboratory [15]. At the beginning of die design stage, DEFORM-3D was used to simulate the forming process and other factors, in order to determine the formability of die design. A model of the hot stamping clinching die is shown on Fig. 6. The forming point is axially symmetrical. To save stimulation time, a one-fourth model was used. The die is made of alloy tool steel SKD 61(DIN-1.2344, AISI-H13). The sheet material is CSC-15B22, which is manufactured by the China Steel Corporation. The chemical composition of CSC-15B22 is shown in Table 3 [19]. The material has ferrite and pearlite structures at room temperature and has a tensile strength of 600 M Pa. The Austenite structure is formed when the material is heated to 850 - 900℃, which increases the ductility. The cooling rate for the quenching process is 30℃/s, which ensures that the micro-structure changes from austenite to martensite, with a corresponding increase in the strength [20]. The detailed simulation parameters are shown in Table 4.