Journal of Materials Processing Technology 214 (2014) 2112–2118

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Mechanical clinching of ultra-high strength steel sheets and strength of joints

Yohei Abe[a,*], Toru Kato[b], Ken-ichiro Mori[a], Shoma Nishino[a]

[a] Department of Mechanical Engineering, Toyohashi University of Technology, Toyohashi, Aichi 441-8580, Japan
[b] Department of Mechanical Engineering, Ishikawa National College of Technology, Ishikawa 929-0342, Japan

ARTICLE INFO

Article history:
Received 15 August 2013
Received in revised form 10 January 2014
Accepted 1 March 2014
Available online 12 March 2014

Keywords:
Joining
Mechanical clinching
Ultra-high strength steel sheet
Fatigue strength
Static strength
Resistance spot welding

ABSTRACT

Ultra-high strength steel sheets having low ductility were joined by mechanical clinching with dies for control of metal flow. The diameter and depth of the die were modified to relieve concentration of deformation of the sheets for avoidance of the occurrence of sheet fracture. As the tensile strength of the steel sheets increased, the interlock decreased due to small metal flow. Two kinds of the ultra-high strength steel sheets having different ductility were used. The ultra-high strength steel sheets having large ductility were successfully joined using die having modified shape, whereas the sheets having small ductility were not joined. The static and fatigue strengths of the mechanically clinched joint were compared with those of the resistance spot welded joint. Although the static load of the mechanically clinched joint was smaller than that of the resistance spot welded joint in both tension-shearing and cross-tension tests, the fatigue load of the clinched joint was larger in the large number of cycles. It was found that mechanical clinching has superior fatigue strength due to the large yield stress of the sheets and relaxation of the stress concentration.

1. Introduction

To reduce the weight of automobiles, the use of high strength steel and aluminium alloy sheets tends to increase because of their high specific strength. For the reduction, mild steel automobile parts tend to be replaced with high strength steel ones. Particularly, ultra-high strength steel sheets having a tensile strength more than 1 GPa are attractive for the reduction. The high strength and ultra-high strength steel parts are conventionally joined by resistance spot welding. For the automobile parts, not only the static strength but also the fatigue strength is important. As the tensile stress of steel sheets increases, the static load of the joint by resistance spot welding becomes large (Futamura and Miura, 2008), whereas the increase in fatigue strength of the joint is not large. In the high strength steel sheets, particularly the ultra-high strength steel sheets, the initiation and propagation of cracks are sensitive (Fujii et al., 2011). It is desirable in automobile industry to develop a joining process for attaining high fatigue strength of joints for the high strength steel sheets.

Galvanised steel sheets having corrosion resistance are useful to improve life of automobiles. In resistance spot welding of galvanised steel sheets, the wear of welding electrode becomes large due to the lower electrical resistance and melting temperature of the coating layer. Zhang et al. (2008) reported that the wear of electrode tips for the galvanised high strength steel sheets was accelerated because of high strength of the sheets. Although Zou et al. (2009) developed coating of electrodes to improve the life, the coating thickness of the galvanised steel sheet is decreased by heating and high pressure during welding.

Mechanical clinching is a cold joining process of sheets by local hemming with a punch and die. The joining process is used in automobile (Barnes and Pashby, 2000), building (Pedreschi and Sinha, 2008), electrical industries. Krause and Chernenkoff (1995) showed that the fatigue load of aluminium alloy sheets joined by mechanical clinching was approximately 25% larger than that by resistance spot welding. Saathoff and Mallick (1998) reported that tool shapes in mechanical clinching affected fatigue strength of the clinched joints of aluminium alloy sheets. Carboni et al. (2006) investigated fracture behaviour and stress distribution in a tensile–shear fatigue test of clinched joints. Mori et al. (2007, 2012) clarified the mechanism of high fatigue strength for aluminium alloy sheets joined by mechanical clinching. The fatigue strength may be superior for not only aluminium alloy sheets but also high strength steel sheets. On the other hand, Varis (2006) reported that the mechanical clinching has the advantage of low running costs without a rivet unlike self-pierce riveting. The corrosion resistance of galvanised steel sheets

* Corresponding author. Tel.: +81 532 44 6705; fax: +81 532 44 6690.
E-mail address: abe@me.tut.ac.jp (Y. Abe).

http://dx.doi.org/10.1016/j.jmatprotec.2014.03.003
0924-0136/© 2014 Published by Elsevier B.V.

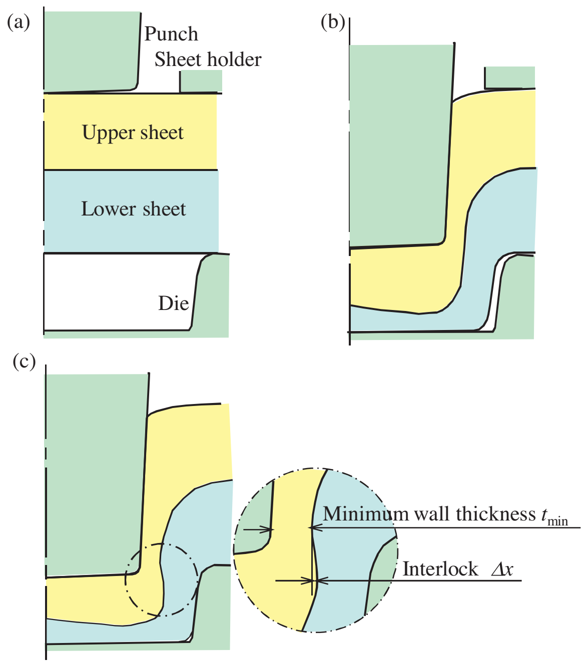

Fig. 1. Mechanical clinching for joining of sheets. (a) Initial, (b) flaring and (c) joining.

joined by mechanical clinching was higher than that by welding (Abe et al., 2010).

Mechanical clinching of ultra-high strength steel sheets is not easy. Although the high strength steel sheets were joined by mechanical clinching (Varis, 2002, 2003), the fracture tends to occur in joining of ultra-high strength steel sheets due to low ductility. Neugebauer et al. (2008) developed a mechanical clinching process with heating dies, and then the magnesium alloy sheets were successfully joined without fracture at high temperatures. However, heating of steel sheets at high temperature is not easy. By using dies for control of the metal flow, not only the mild steel and aluminium alloy sheets (Abe et al., 2007), but also the ultra-high strength steel and aluminium alloy sheets (Abe et al., 2012a) were joined. However, in joining of ultra-high strength steel sheets, the punch load becomes large due to high flow stress of the sheet (Abe et al., 2012b).

In the present study, ultra-high strength steel sheets having low ductility were joined by mechanical clinching with dies for control of metal flow. A shape of the die was optimised to relieve concentration of deformation of the sheets. The static and fatigue strengths of joints of mechanically clinched ultra-high strength steel sheets were compared with those of resistance spot welded sheets.

2. Conditions of mechanical clinching

In mechanical clinching, the sheets are formed by the punch and die to generate the interlock Δx between the lower and the upper sheets as shown in Fig. 1. The upper and lower sheets are joined by being hooked on the interlock generated around the punch corners, whereas the thickness of the upper sheets decreases around this corner. The critical wall thickness of the upper sheet around the punch corner without fracture is required. The fracture of the sheets brings about the corrosion of the parts. Appropriate strength of the joint of the sheets is obtained from the interlock and minimum wall thickness t_{min}.

The material properties of the ultra-high strength steel sheets having a nominal tensile strength of 980 MPa used for mechanical clinching are given in Table 1. The tensile strength and reduction area are measured from uniaxial tension test. Although both sheets

Table 1
Mechanical properties of 980 MPa ultra-high strength steel sheets.

Sheet	Thickness (mm)	Tensile strength (MPa)	Reduction in area (%)
Non-coated (JSC980Y)	1.2	983	62
Galvanised (JAC980Y)		1009	43

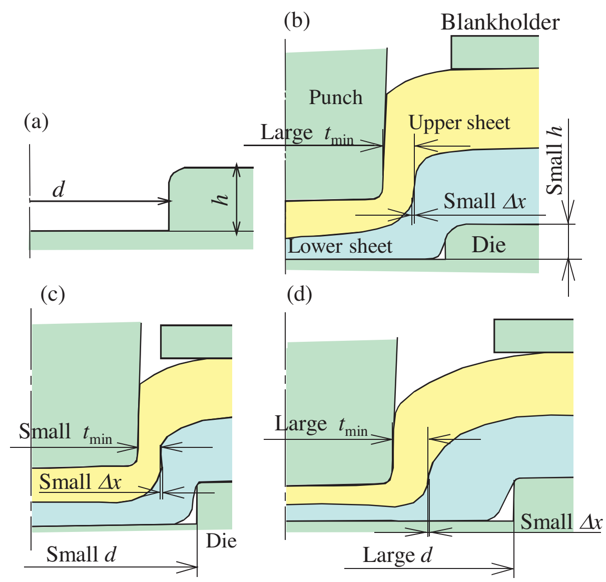

Fig. 2. Effects of depth and diameter of die on metal flow of sheets. (a) Depth h and diameter d of die, (b) small die depth, (c) small die diameter and (d) large die diameter.

have about 1000 MPa of tensile strength, the ductility of the galvanised sheet JAC980Y (Japan Iron and Steel Federation) is lower than that of non-coated sheet JSC980Y (Japan Iron and Steel Federation).

The effects of the depth h and diameter d of the die on metal flow of the sheets are illustrated in Fig. 2. As the die depth decreases, the concentration of deformation around the punch corner is relieved, and thus the fracture of the upper sheet is prevented, the amount of interlock is not sufficient. On the other hand, the amount of interlock is insufficient for excessively small and large diameter of the die.

The tools used for an experiment of mechanical clinching of ultra-high strength steel sheets is illustrated in Fig. 3. To prevent of the plastic deformation of the die, the die having diameter d and

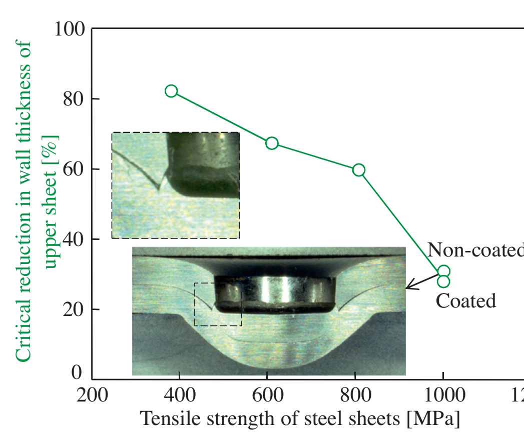

Fig. 3. Tools used for experiment of mechanical clinching of ultra-high strength steel sheets.