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# Experimental Investigation of Resistance Spot Welding of Ultrathin IF Steel Sheets

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## Abstract

Resistance Spot Welding (RSW) is a powerful tool for overlap joint of thin sheets. The welding procedure contributes to affecting the electrical, thermal and mechanical properties of the sheets. In this article, resistance spot welding of ultrathin IF steel sheets (0.67 mm thickness) have been studied. The IF steel sheets were welded by different welding currents (65, 70, 80, 90 and 100 A). The microstructure of the samples was observed using an optical microscope and the tensile test has been carried out to determine the joint strength and fracture mode. The microstructural observations showed that the grain size increase in the fusion zone by increasing the welding current and the heat-affected zone experienced recrystallization and small equiaxed grains were formed in the heat-affected zone. The base metal keeps its high hardness value from the work-hardening induced by the previous rolling process. Best joint strength was obtained at 80 A welding current (2600 N). The fracture mode changes from partial interfacial failure (at lower welding current) to the pullout with tearing of the sheets (at higher welding current).

*Keywords*: Resistance Spot Welding Process; Joint strength, Failure Mode; IF steels.

## 1. Introduction

Interstitial – Free (IF) steels are formable steel grades commonly used in car bodies because of excellent deep draw ability due to its ultralow carbon and nitrogen contents [1–5]. Moreover, in these steels, the titanium, niobium, and vanadium microalloying elements are added to obtain the optimum formability and also to compensate for the loss in strength due to their ultralow carbon content [5, 6]. In addition, the antiaging property of IF steels due to the negligible amount of solute carbon and nitrogen atoms leads to extending the application of IF steels in the automotive industries [7, 8]. Hence, because of the aforementioned characteristics of IF steels, it is often used as rear and front door inners, side panels, spare wheel wells, oil pans, and rear floor pans [4,8,9]. Resistance spot welding (RSW) is widely used in joining sheet metals in auto-body and electronic industries, rail vehicles and home applications (like refrigerators) [10, 11]. Usually in car body up to 5000 resistance spot-welded joints are used [12, 13]. The advantages of RSW process such as Low process time, no requirement to filler metals, welding of thin and ultra-thin sheets and simplicity of operation or automation have led to its widespread use in the automotive industry [11, 12, 14]. A literature survey indicated that although extensive studies have been reported for RSW of steel sheets thicker than 1 mm, there was limited information about RSW of ultra-thin steels (< 0.7 mm) for automotive applications. A few of the early articles have reported some analytical results to investigate the effect

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of steel thickness on heat transfer in resistance spot welding. Gould [15] has investigated the weld development in resistance spot welding of an AISI 1008 steel with different thicknesses of 0.5, 1, and 1.5 mm. He concluded that the thickness considerably affected the ratio of heat transfer into the electrodes and the surrounding sheet. With decreasing the sheet thickness, the heat loss through the electrodes has been increased. Eagar [16] concluded that lower resistance of the substrates happened by decreasing the sheet thickness. By decreasing the sheet thickness, the temperature gradients in the sheet become steeper and a greater portion of the total heat was lost into the electrodes. Gould et al. [17] and Ho et al. [18] concluded that the cooling rate in the RSW process was strongly affected by sheet thickness. By increasing the thickness, the cooling rate was reduced. Williams et al. [19] found that the combination of the variations in heat generation and dissipation due to the variation of sheet thickness would eventually lead to changes in weld nugget shape. Sedighi et al. [20] studied the effect of sheet thickness on residual stresses distribution and nugget size in resistance spot welding of AA6061-T6 aluminum alloys by a two-dimensional coupled electro-thermo-mechanical finite element analysis. The thickness varies from 1 mm to 2.5 mm. The FEM results showed that the residual stresses increase by increasing the welding current and reducing the welding time. In addition, the nugget size increases by increasing the welding current and consequently resulted in an increase in the induced residual stresses. In order to examine the mechanical properties of the joints, the tensile-shear tests are performed and load-displacement diagrams are discussed. Also, during the tensile-shear test, usually two main failure modes, namely interfacial and pullout modes are observed. Investigation of the strength of spot welds and obtained failure mode during tensile-shear test have been studied by many researchers in the recent years [21-26]. For thin sheets, the majority of weld nugget growth occurred rapidly after initial melting, with weld nugget shape being generally elliptical. In addition, based on literature review, decreasing the sheet thickness considerably affected the ratio of heat flow into the electrodes and the sheets. This phenomenon increases the heat loss through the electrode which may increase the electrode tip temperature. Temperature Increase in the electrode tip leads to a considerable reduction in the electrode life [15-17]. Hence, there are many challenges in resistance spot welding process of thin sheets. On the other hand, among the various materials used in the automotive industry, galvanized steel sheets are more commonly employed because of their high corrosion resistance induced by the presence of zinc coating. However, the presence of zinc coating can lead to sensitivity to weld cracking, early wear of electrodes, expulsion, increasing the instability of the welding process, difficulty in controlling the welding parameters and totally reducing the weldability of the galvanized steels compared to conventional uncoated steels [27-29]. Therefore, resistance spot welding process of ultra-thin galvanized IF sheets have numerous challenges. The ultra-thin galvanized interstitial-free (IF) steels are extensively used in the automotive industries. However their resistance spot welding (RSW) process is very important. The IF steels are frequently used as rear and front door inners, side panels, spare wheel wells, oil pans, and rear floor pans [30-32]. Hence, in this paper the resistance spot welding process of ultra-thin galvanized IF sheets has been investigated. The present study was undertaken to understand the variation of joint strength and the mode of failure by the process parameters in resistance spot welding process of IF steel sheets. Also, the microstructural evaluations and hardness tests for different process parameters were studied for resistance spot-welded joints.

## 2. Experimental RSW Procedure

The selected material for investigation is Interstitial Free (IF) steel sheets, which widely used in the automotive industry. The chemical composition of the IF sheets is shown in Table 1. The word "Interstitial Free" (IF) refers to the low content of carbon (and also nitrogen) atoms solute in the bcc iron structure which leads to the low yield strength, high plastic strain range, and good formability. The thickness of the welded sheets is 0.67 mm.

The initial sheets are cut in 150 × 25 mm dimension and placed at overlap position similar to Fig. 1(a). The welding has been carried out at different welding current (60, 65, 70, 80, 90, 100 A) and pulsing time 2 s. The

Table 1. Chemical composition (%) of the IF steel sheets

| Fe | C | Si | S | P | Mn | Ni | N |
|---|---|---|---|---|---|---|---|
| Base | 0.003 | 0.006 | 0.005 | 0.018 | 0.173 | 0.011 | 0.002 |
| Cr | Mo | V | Cu | Al | Nb | Zn | Ti |
| 0.031 | 0.001 | 0.002 | 0.017 | 0.035 | 0.001 | 0.004 | 0.05 |

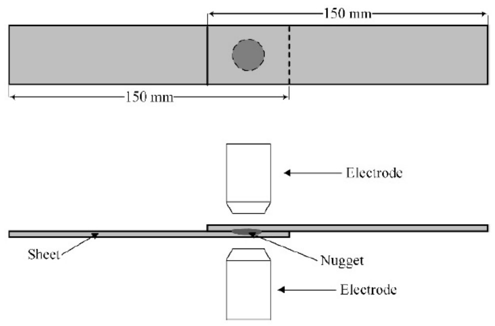
applied load was 200 N. The resistance spot welding machine can prepare 15 KVA power for welding. The welding electrode was made of copper-chromium-zirconium (CCZ) alloy (point type). While welding procedure with the current of 60 A, no melting was observed and the current was not sufficient for joining, thus the current was increased to 65 A to prepare the sufficient thermal energy for joining. Fig. 1(b) shows the welded samples by different current amplitudes. For obtaining the mechanical properties and metallurgical microstructure, five samples of each welding condition were prepared.

## 2. 2. Sample preparation for mechanical and microstructural study

After welding of the samples, the universal tensile test and micro-hardness test were carried out. The simple shearing test can determine the joint strength and the type of fracture mode in RSW. The tensile test was carried out according to ASTM E8/E8M-16a [33] standard code by 1mm/min speed and the results of force-displacement were recorded. Three tensile tests were conducted for each welding current (three replications). In addition, the samples were cut by Wire-Electro-discharge machine (WEDM) and then polished mounted. The hardness test was carried out according to the Vickers test method (ASTM E384- 17 [34]). The 200 g load was applied to the mounted sample as 10 seconds and the diameters of the diagonal indenter were measured after releasing the load. For microstructural observation, the samples were polished and then etched by Nital reagent (5 mL $HNO_3$+ 95 mL $C_2H_5OH$ ethanol). The etching time was about 10 seconds and the samples were washed and dried later. An OLYMPUS optical microscope was used to observe the microstructure of samples.

## 3. Results and Discussion

In this section firstly microstructural evaluation will be discussed then the results of the tensile test of welded samples will be presented and conferred.




(a)

(b)

Fig. 1. a) The configuration of joining by RSW b) The welded sample by RSW.

### 3. 1. Results of Microstructural Observation and Hardness Measurement

Fig. 2 shows the cross-section of the welding zone including the fusion zone and the macroscopic view of the sheets from a side view. The nugget size increased by increasing the welding current and due to higher generated heat, penetration increased and the total thickness of the sheets decreased.

Fig. 3 shows the results of hardness tests on the welded samples in different zones of the welding. The hardness value decreased from the base metal to the fusion zone. At the welding current of 80 A, the magnitude of hardness was almost equal in the fusion zone and heat-affected zone. Fig. 4 shows the microstructure of the samples with the welding current of 70, 80, and 90 A. From Fig. 4 it can be concluded that the grains were smaller at 70 A welding current because of the low generated heat in the welding. The temperature dropped below the austenitic transfer temperature and the dendritic grains could not grow. By increasing the welding current, the fusion zone experienced higher temperatures and the grains had enough time to grow. Also, according to the chemical composition of the IF steel (Table 1), the weight percent of alloying elements is noticeably low, therefore, the martensitic transformation could not be happened especially due to the low content of carbon atoms and a ferritic phase would be created in the fusion zone. Fig. 5 shows the microstructure of the fusion zone and heat-affected zone along with the welded sample at 90 A welding current. The grains were smaller in the heat-affected zone and it seems that the recrystallization was happened and small equiaxed grains were formed in the heat-affected zone. The microstructure of the heat-affected zone proves the value of hardness in Fig. 3 in which recrystallization and stress release decreased the hardness in comparison to the base metal and fusion zone.

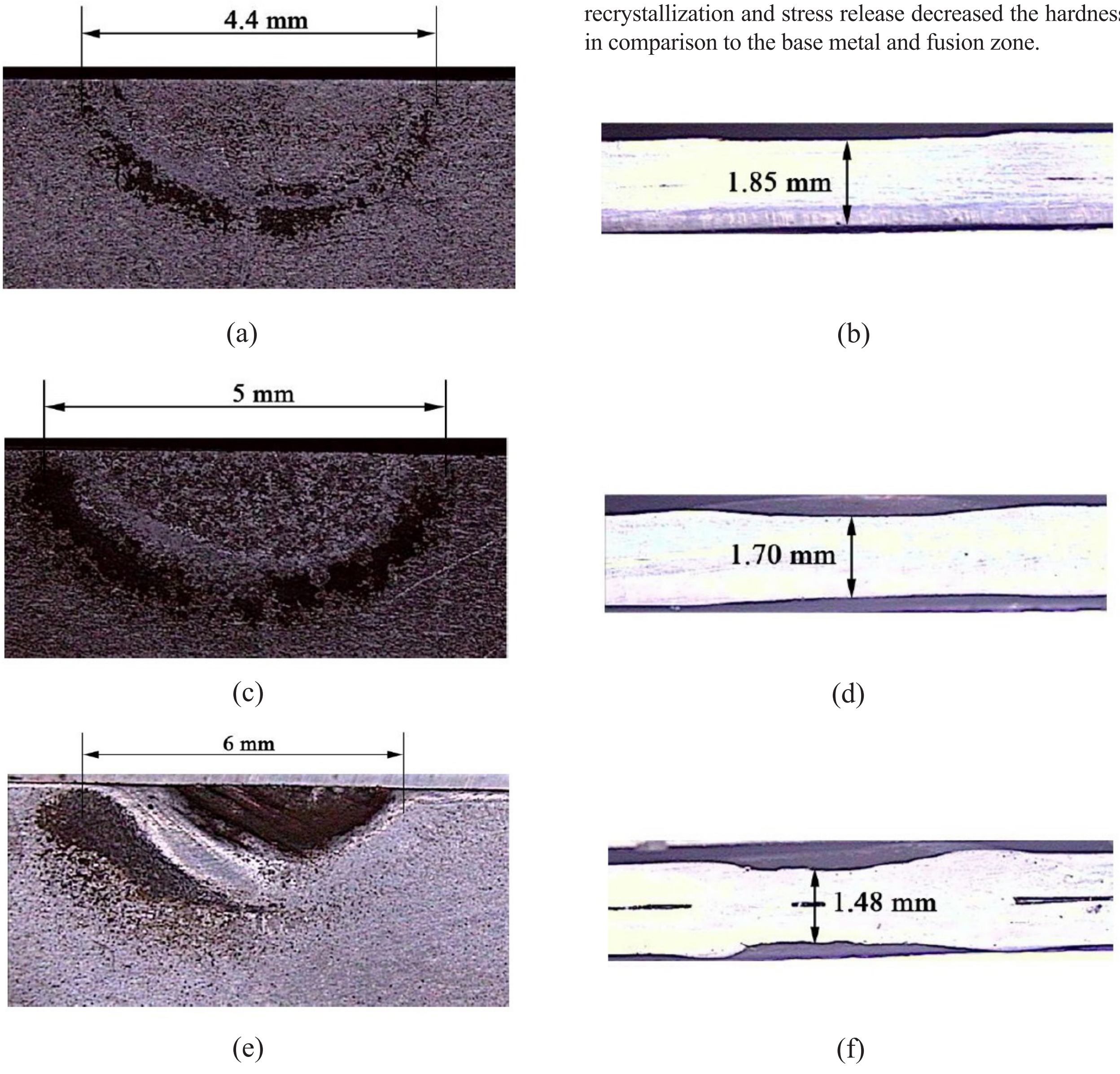



Fig. 2. The cross-section of nugget and macroscopic view of the joint a, b) 70 A current c, d) 80 A current e, f) 90 A current.

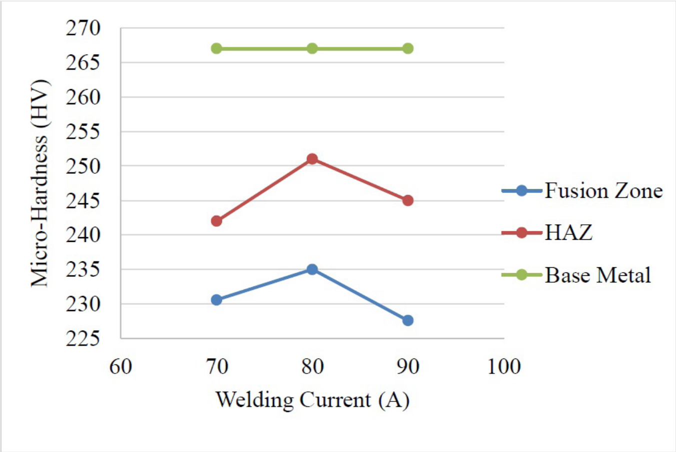



Fig. 3. Comparison of the hardness in different zones of the welded samples.

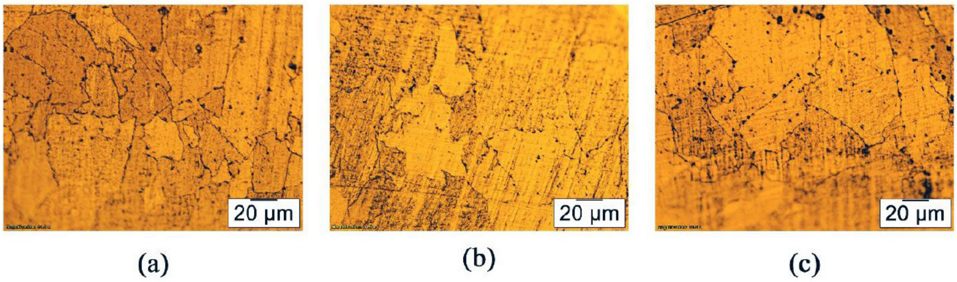



Fig. 4. The microstructure of the welding zone a) 70 A current b) 80 A current c) 90 A current.

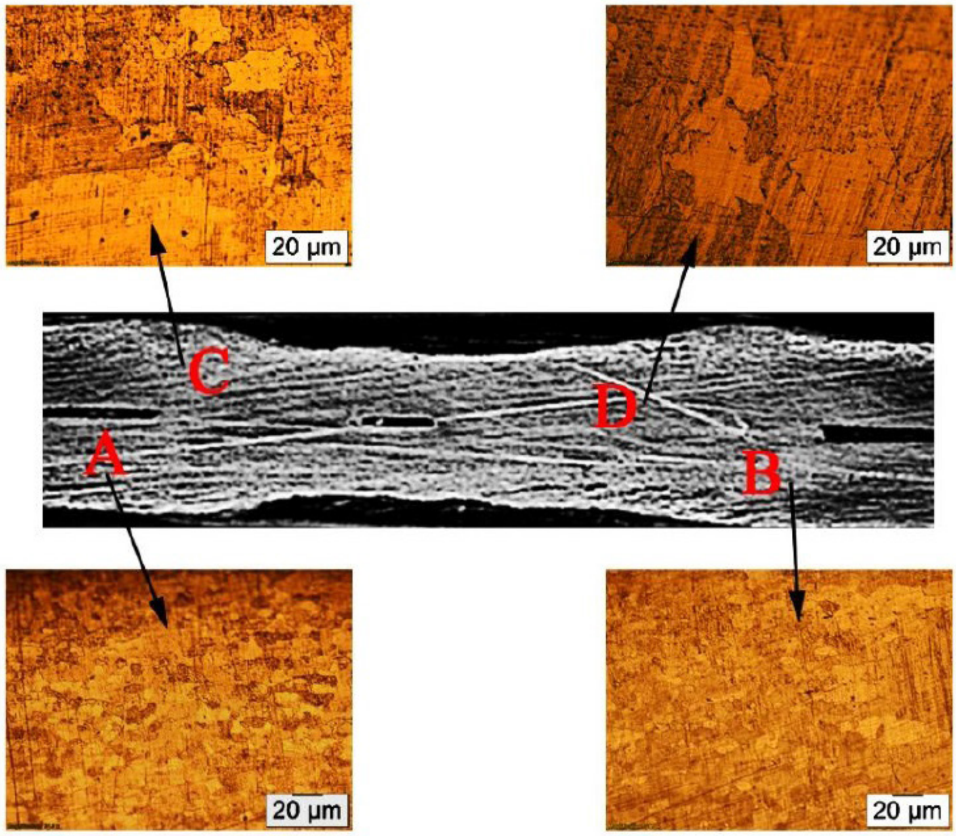



Fig. 5. The microstructure of the different zones of joint at 90 A welding current.

### 3. 2. Results of Tensile test

Fig. 6 shows the result of the tensile test for welded samples. The strength of the welded samples increased by increasing the welding current from 65 A to 80 A. Above the 80 A welding current, the strength decreased. Fig. 7 shows the maximum load bear by the sample. The maximum load increased to 2600 N (elongation 4.36%) and then decreased. By increasing the welding current, the generated heat in the contact zone between the electrodes and the sheets would be increased, consequently, the sheets started to melt from the interface of the sheets and better cohesion would be obtained by applying the external load. This would cause an increase in the strength of the joint. But for the welding currents higher than 80 A, the extra generated heat due to the electrical resistance of the sheets while passing through the sheets increased the temperature and led to decreasing the

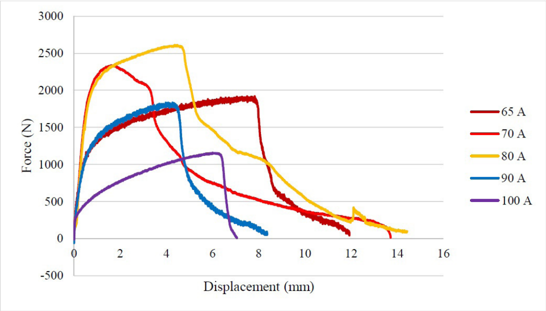



Fig. 6. Comparison of the results of the tensile test for different welded samples.

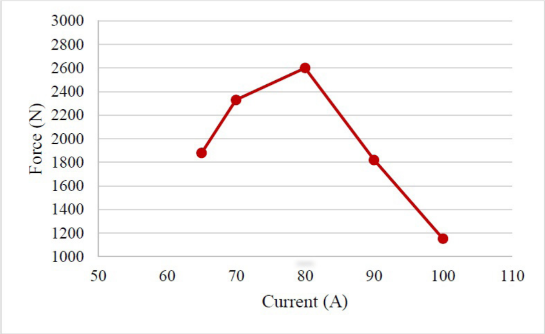



Fig. 7. Variation of the maximum force obtained from the tensile test by the welding current.

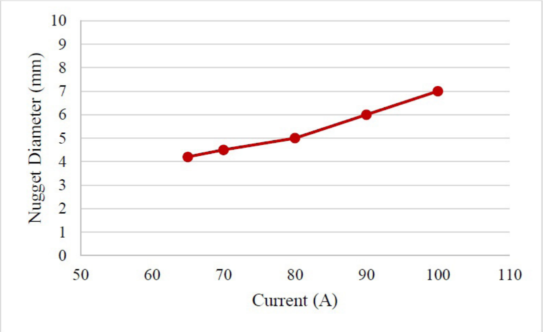



Fig. 8. Variation of the nugget diameter by the welding current.

thickness in the welding zone. The thickness of sheets was very low and at a higher temperature, the external force extruded the material from the fusion zone. Also, from microstructural observation, it can be inferred that the grain size in the fusion zone increased for the welding currents higher than 80 A. The generated extra heat at higher welding currents led to a higher temperature in the fusion zone and the grains had enough time to grow. Nevertheless, the strength locally decreased by increasing the grain size but the total strength, depended on the weakest point of the sample. The nugget size varied by the welding current shown in Fig. 8. As can be seen, the nugget size increased from 4.2 mm to 5 mm by increasing the welding current from 65 A to 80 A. But the rate of increase in the nugget size increased at the welding currents higher than 80 A, which shows the extruding of the melted material from the interface.

Fig. 9 shows the samples after the tensile test. Three different fracture modes are observed, partial interfacial mode, pullout mode and pullout mode with tearing of the sheets. The mode of fracture changes from partial interfacial mode to the pullout mode with tearing by increasing the welding current (Fig. 10).

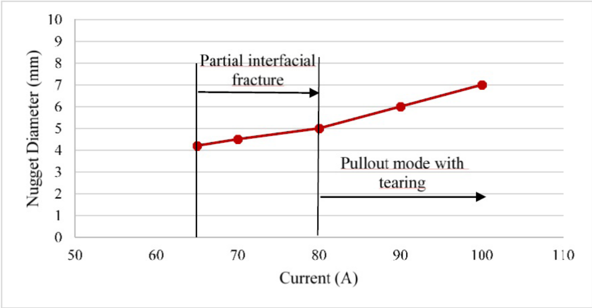



Fig. 9. The mode of fracture for welded samples a) partial interfacial mode (65 A), b) pullout mode (80 A), c) pullout mode with tearing of the sheet (90 A).

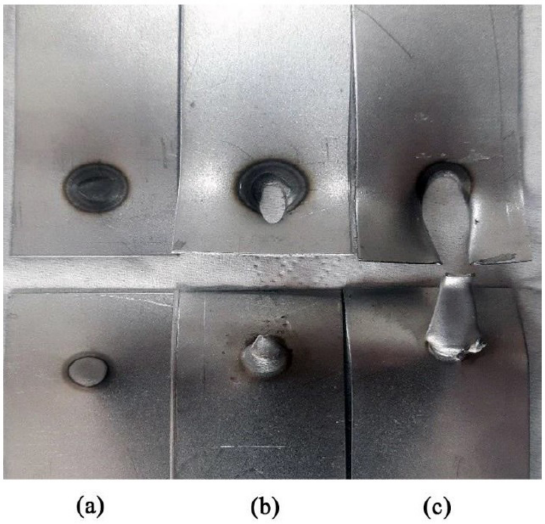



Fig. 10. Variation of the mode of fracture for different welding currents.

In resistance spot welding, the stress in the interfacial layer of the sheets is typically shear stress. In other welding zones, the stress is tension-shear type. Shear stresses produce interfacial fracture mode in the welded samples while tensile stresses lead to pullout fracture mode or pullout with tearing mode. An important parameter of the welding process which controls the stress distribution in the resistance spot welding is the nugget size. By decreasing the nugget size, the shear stresses in the interfacial zone of the nugget reach the critical value of strength before the tensile strength in the welding zone reaches the critical value of strength and interfacial failure mode in the interface would be happened. On the other side, when the diameter of nugget increases from a specified diameter, the shear stress in the interface of the sheets would not reach the critical value of crack propagation inside the fusion zone. Therefore, the tensile stresses cause the pullout fracture mode happen instead of partial interfacial fracture mode (Fig. 10).

## 4. Conclusions

In current article, the resistance spot welding of ultra-thin IF steel sheets was investigated experimentally. The main findings of the article can be listed as follows:

- The grains grow in the fusion zone due to the generated heat in RSW and smaller grains were obtained in the heat-affected zone due to the recrystallization.
- The strength of the welded samples increased by increasing the welding current from 65 A to 80 A and then the strength decreased beyond the welding currents of 80 A.
- By increasing the welding current from 80 A, the mode of fracture changed from partial interfacial mode to the pullout mode with tearing.
- Good joint strength, higher hardness value in the fusion zone and enough heat generation to weld the ultrathin sheets were obtained at welding current of 80 A.

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