RESEARCH ARTICLE OPEN ACCESS

# “The Effect of Welding of the Formability Of the Carbon Steel Sheet”

TAREQ H A H ALKHUDHER.
NABEEL E S BOUGHAITH.

**ABSTRACT**
The meaning of the Forming limit diagram “FLD” is considered to be an important tool in determining the forming of sheet metal . there is yield limit curve “FLC” for each sheet that shows its formability , stress limits and yield zones. Sometimes it is necessary to join two or more sheets of different thickness end to end to obtain a single part will be formed later . as in some parts of the body of a car . in this paper , the effect of electric arc welding on the boundary diagram of the forming of the carbon steel was studied . it has been observed the welding affects the formation limit curve , where the main and minor stresses decrease for the steel sheet .

**Keywords:** {welding – formability – Formability limit diagram }

---

Date of Submission: 13-10-2024 Date of acceptance: 27-10-2024

---

## I. Introduction

Metal sheet forming processes account for a significant portion of metal forming operations. These processes are involved in producing the external structure of automobiles, including doors, hoods, fenders, and more. The sheet metal forming process is one of the final operations performed on the sheets, and it heavily relies on several variables such as the metal’s properties, its behavior during forming, lubrication, and forming equipment.

Each metal or alloy has forming limits in metal sheet forming processes. These limits are measured by the metal's formability using the limiting forming diagram (LFD), which represents the maximum principal and secondary strain limits on the sheet surface. This curve separates the safe forming region from the failure region and helps identify critical forming zones for each metal.

Since the introduction of the forming limit curve (FLC) by researchers
[i]*Keeler and Backofen (1963)*, who determined the right-hand side of the curve, *followed by* [ii]*Goodwin (1968),* who completed the left-hand side, various methods have been explored to experimentally determine the FLC. Different shapes of punches have been used, such as hemispherical*, flat circular, elliptical, and*
[iii] *rectangular punches* The hemispherical punch has been utilized by many researchers, including Veerman *and* [vi] *Hartman (2001),* [v] *Shakeri and Darinai (2012)*, and [iv] *Kim et al. (2003),* using stretch and draw tests to determine the forming limit curve for metal sheets. The specimens were designed to produce strain paths ranging from uniaxial tension to near equi-biaxial stretching.

Previous research has focused on determining the forming limit diagrams (FLDs) for sheets of a constant thickness intended for forming. However, it may sometimes be necessary to form sheets with varying thicknesses, as in some parts of a sedan car, such as the floor, rear door lining, side body base, spare wheel panel, and roof cover. This necessitates studying the effect of welding on the formability of sheets intended for forming. In this study, the effect of manual electric arc welding on the formability of a carbon steel sheet containing approximately 0.4% carbon was investigated by constructing its forming limit curve before and after welding.

### Experimental Work

The study was conducted on carbon steel sheets with a thickness of 1 mm, and the carbon content was estimated based on the pearlite and ferrite fractions using microscopic examination. The carbon content was approximately 0.4%. To construct the forming limit diagram, which plots the strain path from uniaxial tension to equi-biaxial strain, specimens with dimensions shown in Figure 1 [vii] were prepared. Eight different shapes of non-welded sheet specimens (two for each shape) were prepared, as well as the same number and shapes for welded specimens, using manual electric arc welding at the center. The specimens were divided into two types: the first type (1-4) consisted of four specimens with the same length (100 mm) and different widths (37.5, 50, 62.5, 75 mm), with 25 mm radius discs on both sides of each specimen to plot the left side of the curve, i.e., from the plane strain path to the uniaxial tension path. The specimens were cut using a specially designed die (Figure 2). To plot the right side of the forming limit curve, the second type of specimen (5-8) was used, consisting of four specimens with the same length (100 mm) and different widths (62.5, 75, 87.5, and 100 mm).

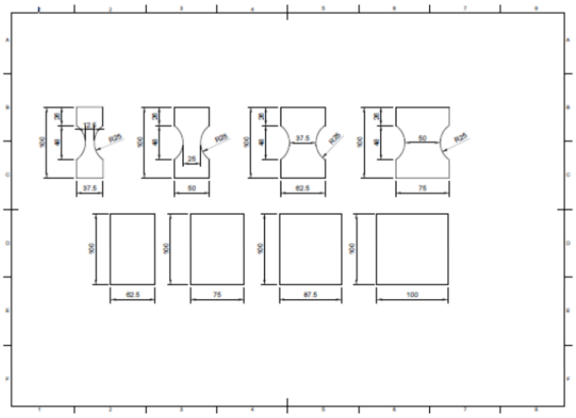



**Figure (1)**: Dimensions of the specimens used to determine the forming limit curve

To measure the true strain and determine the strain limit, circles with a diameter of 2 mm were printed on the surface of the specimens before the forming process. The accuracy of the dimensions was verified using a portable measuring microscope with a precision of 0.01 mm. After printing the circles, the forming process began using a punch with a hemispherical head, 50 mm in diameter, and a die 52 mm in diameter, along with a blank holder made of the same material, secured by ten bolts, as shown in Figure (3).

A tensile testing machine was used as a press during the forming process. The die was mounted on the press, and the eight specimens were sequentially fixed using the blank holder (Figure 3). The punch speed was set to 20 mm/min, and the process was halted when the load indicator on the machine began to drop, indicating necking or fracture in the specimen.

[viii] The Hecker method was followed to determine the strain limit, where the printed circles (which become ellipses after forming) were categorized as "Accepted," "Necked," or "Fractured."

Hardness measurements were taken across the welded zone, the heat-affected zone (HAZ), and the unaffected base metal using a hardness testing device. (Brooks Inspection equipment )

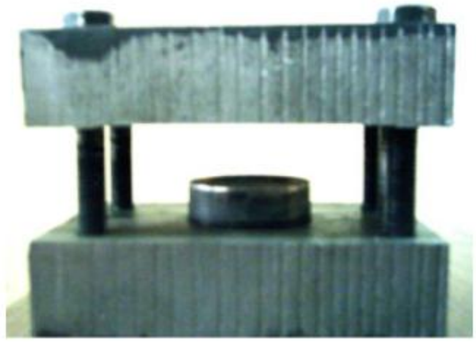


Figure (2): Shows the die used for cutting the curvature

Figure (3): Shows the components of the drawing die

## II. Results and Discussion

The forming limit curves (FLCs) for the steel sheets used in this study were determined both before and after the welding process. This was done by calculating the true strains (ε1, ε2) after measuring the accepted, necked, and fractured circles for each specimen (Figure 4), following the **Hecker method** [viii], and identifying these strains relative to the major and minor axes

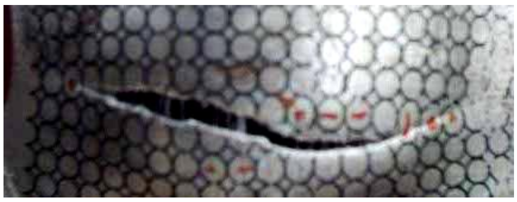


Figure (4): The fracture zone showing the accepted, necked, and fractured ellipses

The true strains were calculated using the following :equations (see Figure 5)

$$d\varepsilon = d(d)/d$$

$$\varepsilon 1 = \int_{d0}^{d1} d(d)/d$$

*ISSN: 2248-9622, Vol. 14, Issue 10, October 2024, pp 106-111*

$$\varepsilon 2 = \int_{d0}^{d2} d(d)/d$$

$$\varepsilon 1 = ln\frac{d1}{d0} \ldots \ldots \ldots \ldots \text{(1) Major Strain}$$

$$\varepsilon 2 = ln\frac{d1}{d0} \ldots \ldots \ldots \ldots \text{(2 ) Minor Strain}$$

Where:

- do): Diameter of the circle before forming
- d1): Major axis of the ellipse after forming
- d2): Minor axis of the ellipse after forming

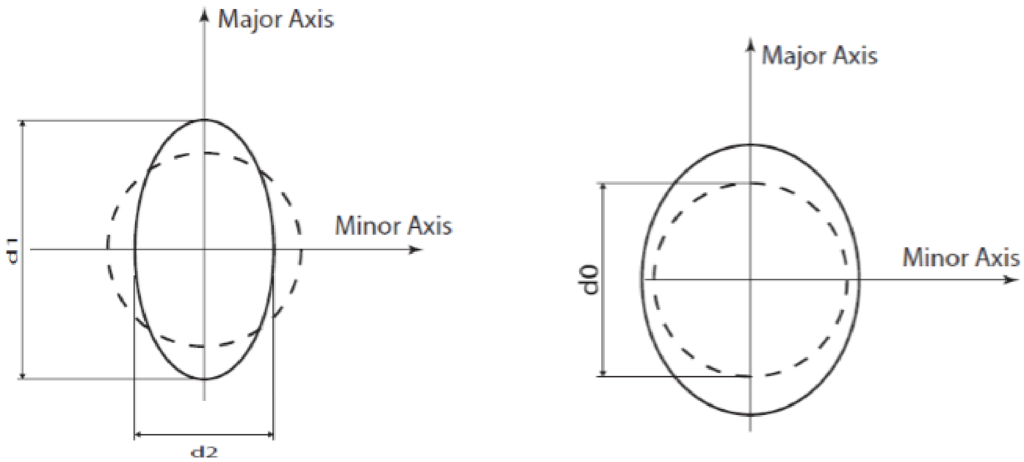



**Figure (5): Illustrates the circle before and after the forming process for the uniaxial and equi-biaxial strain paths**

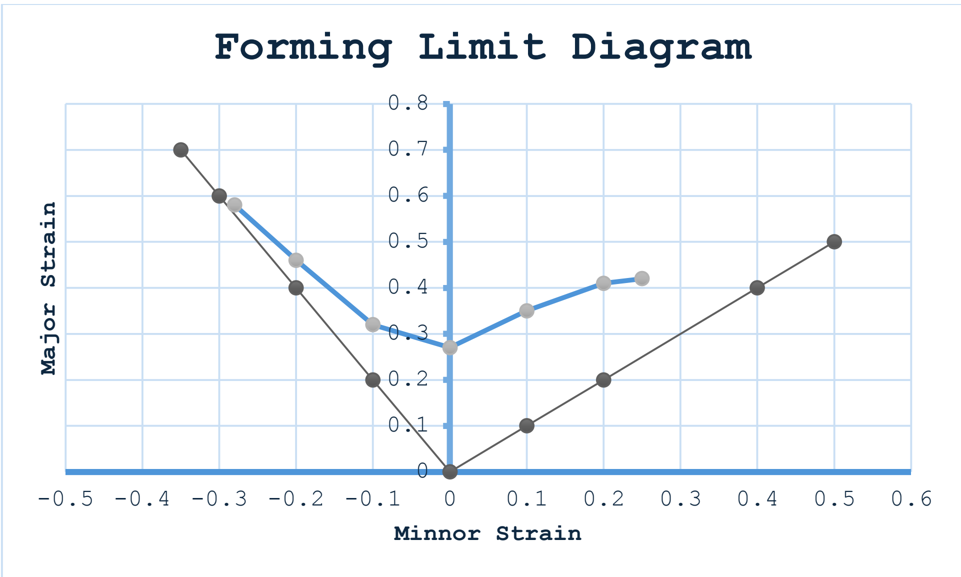



Figure (6): Forming limit diagram for non-welded steel sheets

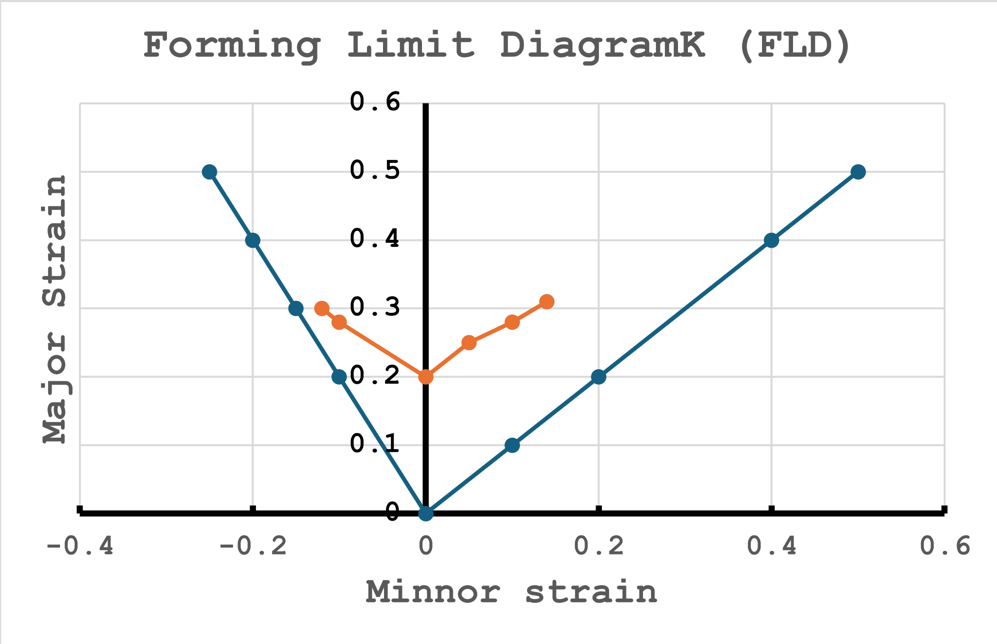



Figure (7) shows the Forming Limit Diagram (FLD) for welded steel sheets.

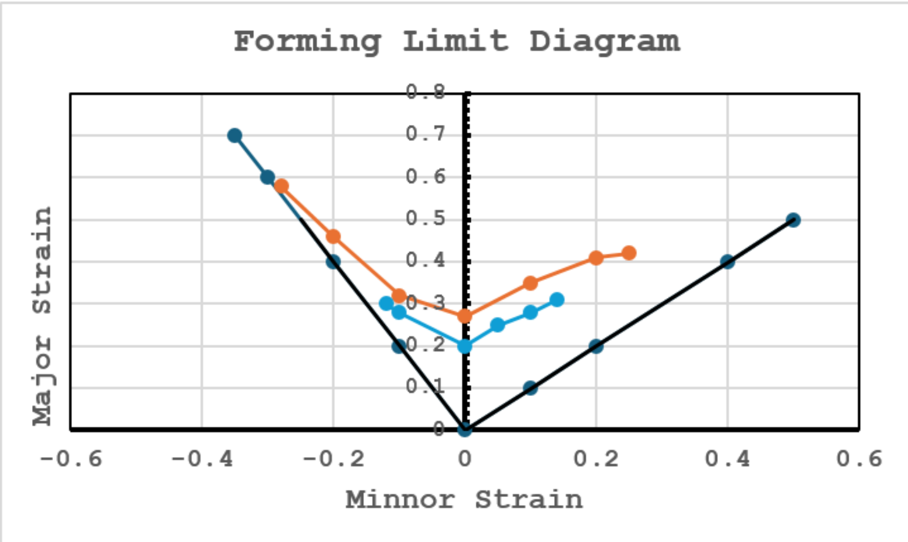



Figure (8) shows a comparison between the Forming Limit Curves (FLCs) for welded and non-welded sheets,

where the effect of welding on formability is clearly represented by the forming limit curve. The major strain decreased for all paths due to the welding effect, as did the minor strain.

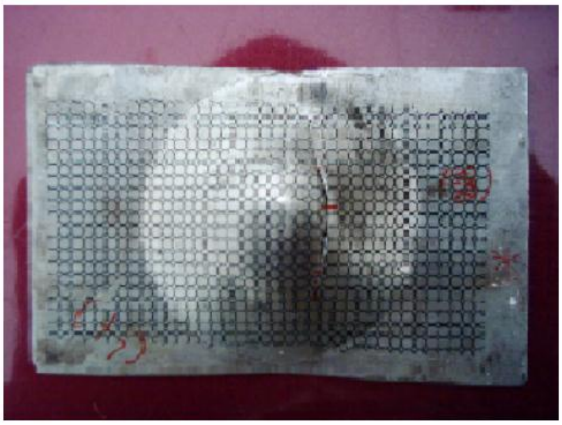
It is observed from Figures (9a and 9b) that necking and fracture in non-welded samples occurred away from the pole, while in the welded samples (Figures 10a and 10b), necking and fracture occurred near the pole in the heat-affected zone (HAZ). During the forming process, when the hemispherical punch contacts the sheet and the drawing process begins, the tension in the sheet increases with the punch's movement. In the absence of friction between the sheet and the punch, the highest tension and strain occur at the pole, leading to necking and failure in the form of tearing. However, in practice, due to the presence of friction (as in this study), the distribution of major strain from the pole to the clamping edge will be shown in Figure (11) [ ix] .

(a)

(b)

Figure (9): Two photographs of specimens No. 4 (a) and No. 5 (b) (the non-welded specimens).

(a)



(b)

Figure (10): Two photographs of specimens No. 4 (a) and No. 5 (b) (the welded specimens).

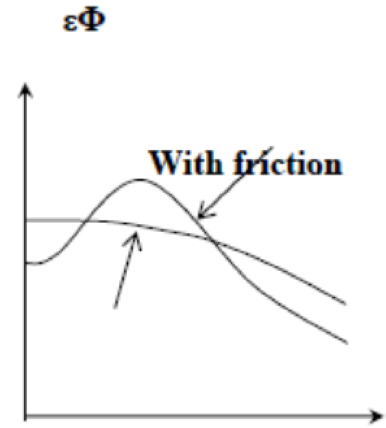



Figure 11: Strain distribution of a formed sheet using a hemispherical punch (ix)

εΦ= Major Strain
r = Distance to the center

Due to the contact friction stress (μP) directed toward the pole, the highest tensile stress and the largest strain occur at a distance from the pole, where necking or fracture takes place. Figure (9) shows the location of the fracture in specimens 4 and 5 of the non-welded sheet, which is farther from the pole compared to the welded specimens (Figure 10a and 10b).

For the reasons mentioned above, in the case of welded specimens, and due to the exposure of the sheet near the weld area (the Heat Affected Zone (HAZ)) to high temperatures (reaching the austenite phase in some areas), changes occur in the metal structure, leading to an increase in hardness in the HAZ [x]. Figure (12) shows the hardness distribution (HRB) from the weld center to the unaffected zone of the sheet used in the study before the forming process.

As is well-known, the increase in hardness in this region is accompanied by a decrease in ductility, which leads to early necking and failure in the HAZ at a lower strain compared to the non-welded sheet. This ultimately results in reduced formability, significantly lowering the Forming Limit Curve (FLC), as shown in Figure (8), where the reduction was approximately over 20%. This explains the occurrence of fracture in the HAZ, as shown in Figure (10)

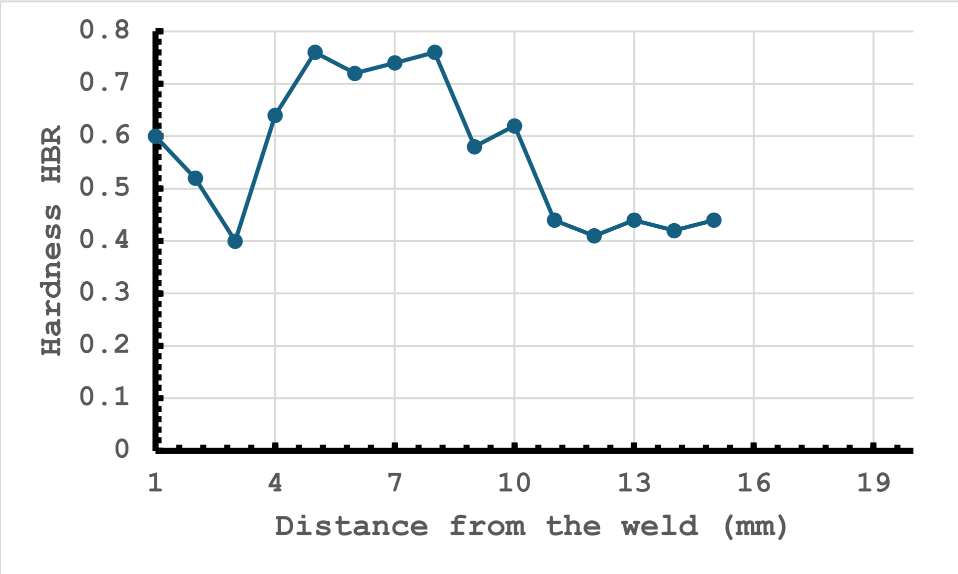



Figure (12): Hardness (HRB) distribution from the weld center to the unaffected area of the sheet.

## III. Conclusions

When welding carbon steel sheets and forming them using a hemispherical punch, and comparing their formability to non-welded sheets, the following conclusions can be drawn:

a. The welding process leads to an increase in hardness in the Heat Affected Zone (HAZ), which is accompanied by a decrease in ductility in this area.

b. Necking and failure occur under lower stresses and strains compared to the non-welded sheet, which results in a decrease in the Forming Limit Curve (FLC) of the sheet, significantly reducing its formability.

c. In welded sheets, most fractures occurred in the Heat Affected Zone (HAZ), while in non-welded sheets, fractures occurred farther from the pole.

## References

[1] Keeler S.P. and the Backofen W.A. (1963) Instability of Plastic and Fracture in the Sheets Stretched Over the Rigid Punches, Transaction of The ASM,Vol.55,25-41.

[2] Goodwin G.M. (1968), the Application of Strain Analysis corresponding to Metal Forming, Society Sheet of the Automotive Engineers, Technical Paper No 680093.

[3] Maciniak, Z., Kuczynski K and Pokrra,T (1973) the Influence of the Plastic Properties of a Material on Forming Limit Diagram for the tension of the Sheet Metal in T, Int. J. Mech. Sci, Vol.15 pp.789-805.

[4] Verman,C.C. Hartman,L.Peels, J.J. Determination of the Appearing Strain and the Admissible Strain in Cold of Reducing Sheets, Inducting of the Sheet Metal, Vol.98,1971 pp 678-680.

[5] Shakeri,M.A. and Dariani ,B.M." Experimental and Theoretical Analysis of Sheet Metal Formability Limits",Rev. Met. CIT Sci.Genie Mater.,May 2000,663-670.

[6] Choi,S.H and Kim K.J. .," Formability of AA5182/Polypropylene/ AA5182 Sandwich Sheets, Journal of Material Processing Technology139 (2018).

[7] Hitchcok http://www.surfacestrain.comUSA LLC .

[8] Hecker, S.S., (1999) "Simple Technique for Determining Forming Limit Curve" Inducting of the Sheet Metal, pp.671-676.

[9] S.J.Hui 2015 , and Z.Marcinal, J.L.Duncan "Mechanics of sheet Metal Forming "Butterworth Heinemann,pp132-133.

[10] Bolton, W.,( 2009). Technology of Engineering Materials. Butterworth Heinmann PP 384.