

# The Influence of Weld Joint position in Low Carbon Steel on Fatigue Life

**Ezzet Hameed Abdulsalam**

Department of Mechanical Power Technical Engineering- (Refrigeration & Air Conditioning), University of Dijlah, Baghdad, Iraq

---

## Article Info

### Article history:

Received May, 10, 2026

Revised May,30,2026

Accepted Jun.,15,2026

---

### Keywords:

Fatigue crack

Weld joint

Residual stresses

---

## ABSTRACT

The influence of weld residual stress on crack propagation under fatigue loading of mild steels has been investigated using compact tension specimens (C.T.S). The residual stresses were formed due to welding processes. Both hardness and longitudinal residual strain were measured using standard hardness test and strain gauges technique. Experiments were conducted to calculate the retardation fatigue crack propagation rate (FCPR) due to thermal stresses. Test is done on welded compact tension specimen (C.T.S). The experimental results confirmed that high hardness formed in the welding region as well as in the heat affected zone. Also, high tensile longitudinal residual strain was observed in weld metal and heat affected zone (HAZ) followed by compressive residual strain. Fatigue tests revealed that higher (FCPR) in both weld metal zone due to longitudinal residual stresses, while the compressive residual stresses reduced the (FCPR) and sometimes stopped it

---

### Corresponding Author:

**Ezzet Hameed Abdulsalam**

Department of Mechanical Power Technical Engineering, University of Dijlah

Almasafi street, Baghdad, Iraq

Email: izzat.hameed@duc.edu.iq

---

## 1. INTRODUCTION

Fatigue crack is a normal failure that may happen in any structures when is subjected to cyclic type of loading such as bridge, air craft, ships, moving machine components.... etc. Fatigue failures are represented around 90% in metals, polymers and ceramic. Under fatigue loading, it is found that failure occurs at stress less than that of tensile static load. Paris et al, the first to create the fatigue crack propagation rate per stress cycle, where  $da/dn$ , is related to stress intensity factor range,  $\Delta K$ ,  $da/dn=C(\Delta K)^m$  [1, 2]. This recognize that all structures are flawed, and that cracks may initiate early in service and then propagate sub critically. Lifetime is considered as a number of loading cycles for crack grow to failure [2]. Accounting for the effects of metal fatigue plays a major role in the design of optimized aerospace structures [3].

Residual stresses develop in welded joints as a result of differential weld thermal cycle (heating and cooling during welding) affected weld metals and zone near to the heat affected zone (HAZ). The form and degree of residual stress changed through different passes of weld i.e. that's mean heating followed by cooling may create compressive residual stress in base metal.

Maximum of compressive residual stress then gradually decreases and soften of the metal which was being heated. The Compressive residual stress closes the surface could reduce to zero degree during cooling process of the welding. Through cooling process, the metal begins to shrink which lead to create tensile residual stresses and continue increasing in their magnitude until arrives room temperature. The Presence residual stresses may be considered as a main reason for failures to be occurred under many types of loading, while compressive residual stresses could decrease the tendency of failure to occur and it considered as the main factor for fatigue life in many

structures [4,5,6]. The phenomena elasticity is a suitable criterion to consider the effect of residual stresses field on the growth of fatigue crack [7]. It is mentioned that the amount of and the re-distribution are not affected by the formation of the small amount of plasticity combined with the fatigue crack propagation [8]. Residual stresses are an important parameter to be considered for confirmation of the weld quality which may cause a failure in places of weld zone in several applications [9, 10].

## 2- Experimental Procedure:

### 2-1. The Material

The material investigated in the present research is mild steel with butt weld joint design. The chemical composition of the base metal is 0.2%C, 0.68%Mn, 0.29%Si, 0.025%S, 0.011%Ni, 0.06%Mo while the percentage of elements for the weld is 0.11%C, 0.99%Mn, 0.22%Si, 0.07%Mo, 0.013%S, 0.013%Ni.

The microstructure investigation was done for both base and welded metals which are mainly contain pearlite phase (dark regions) and a ferrite phase (bright regions). The elongated of pearlite and ferrite phases reveal the rolling direction of the used steel plate, while the coarse grains in weld zone is referred to the weld microstructure of the weld metals which is also show of pearlite and ferrite phases as shown in figure 1.(A,B,C).

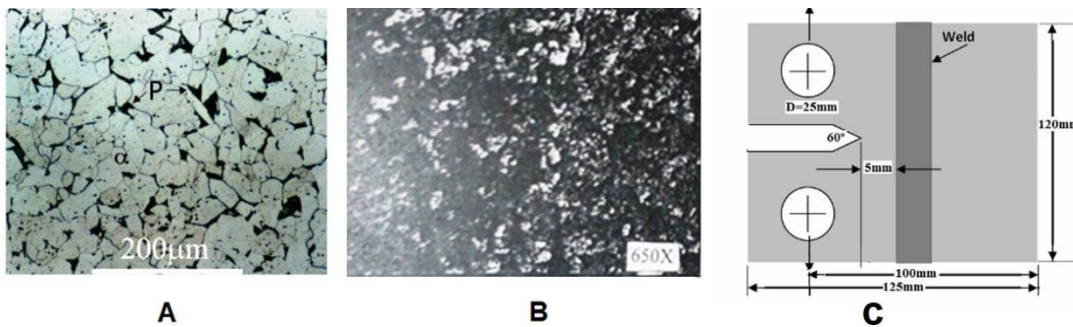


Figure (1): (A&B). Microstructures of Base Metal & Weld Metal, (C). Welded CTS

### 2.2. Tensile Test:

Tensile specimen made from base metal with weld joint at the middle of the specimen gauge length were prepared using ASTM standard E8-87 [8]. The welded tensile specimen is shown in Figure (2).



Figure (2): Welded Tensile Test Specimens

The mechanical properties obtained of for base metal and welded are listed in table (1).

Table (1): The Tensile Properties of the Base & Weld Metal.

Materials	Yield stress (MPa)	Tensile Strength (MPa)	Young Modulus (MPa)	Elongation%
Base Metal	290	445	206	64
Weld Metal	310	454	194	61

### 2.3. Fatigue Tests:

#### A- Fatigue specimen:

CTS, of 10 mm thick was machined from plate of 12.7 mm of rolled low steel panel. The notch position created in the base metal when the crack plane parallel to the rolling direction. The specimens were notched to reduce the number of cycles for initiation fatigue crack as shown in figure (2 C). EDM machine was used to initiate notch with tip radius of 0.2 mm.

The welding process was conducted using shield metal Arc Welding (SMAW) machine Type Lincoln Model (R3R-

%500), Weld joint type V-groove had been produced using mechanical machining. The weld joints were cleaned to be free from any rust, oil, water, paint and any foreign particles. A multi-layer Shield metal arc welding sequence was used to produce a number of welds passes for complete welding processes around (4 to 5) passes for each specimen.

A direct current (DC) and voltage were used with range of (160 -170 Ampere) and (20 -22) Volt respectively. The filler metal used in this work is AWS E6013 of 3.175 mm in diameter, where the standard properties of this filler is very close to that of the base metal.

#### B- Fatigue Test.

Fatigue crack propagation tests on CTS were conducted using servo pulser type 4880 controller machine with a test frequency of 30 HZ. Crack propagation was measured using clip gauge to measure the crack displacement (COD), details of the principle of working of this instrument is and measurement procedure are explained in reference [24]. All fatigue tests were conducted under the following loading condition, ( $P_{max} = 14700$  N, load ratio,  $R = P_{min}/P_{max} = 0.6$  and Frequency = 30 HZ). The crack lengths and the number of cycles were recorded and the results were plotted in a form of curves as in figure (3).

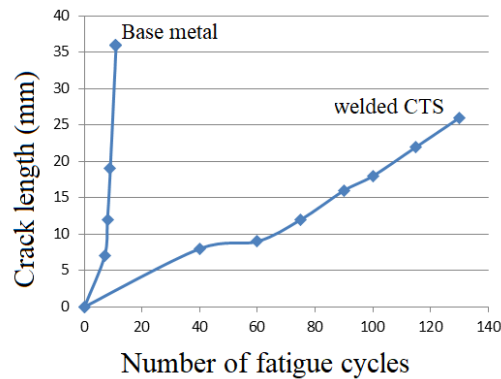


Figure (3): Crack Length versus No. of cycles

#### 2.4. Residual Stress Measurement:

The hole drilling strain gauge was used to determine the number of residual stresses and strains. This process depend on drilling holes in the specimens in order to measure the measure the of strain close to the hole [13]. This method had been restricted only to determine the average stresses in the surface layer of the part that is penetrated by the drilled hole [14]. So that if the size of the strain gauge decreases, the accuracy of the strain measuring increases. The strain gauges were fixes along the centerline bisecting the obtuse angle ( $120^{\circ}$ ) between the two welding lines to measure the longitudinal residual strains as in Figure (1, C).

#### 2.5. Hardness test of welding:

Rockwell hardness equipment was used to measure the hardness of the weld starting from the center line of weld joint toward base metal, that was conducted to show how hardness changed with temperature along the weld, Heat affected zone and base metal, the maximum hardness number was existed at the weld center line and start to decrease in value toward the HAZ and base metal.

### 3. RESULTS AND DISCUSSION (10 PT)

From experimental results, it was confirmed that, the heat distribution perpendicular to the weld line was decreased with the increasing of distance from weld line, the maximum temperature at pass four near the weld line. The influence of heating process extended in the range of (18-20 mm) where it is measured from the Centre line of the heating source. This region included the weld metal and HAZ. A similar result was reported by K Masubuchi [40] on 5050-H32 Al- weldment.

It was found that, a large number of hardness occurred at weld joint and HAZ. The reason for this distribution was due to the random distribution of the heat of welded specimens; the same result was obtained by Itoh et al [15] for austenitic stainless steel and C-Mn- Si steel.

The high longitudinal tensile residual strain in weld metal region. The tensile residual strain decreased through HAZ to diminish at a distance of about (12 mm). The zone of the tensile residual strain was followed by a zone of compressive strain which had a maximum value at a distance of about (24 mm). The residual strain distribution gives a strong indication about residual stresses distribution which is a maximum value at a distance of about (24 mm). Same results were reported by Masubuchi on Al alloy and Titanium weldment [11], by [16] in C-Mn Micro

alloyed, stainless steel and [17] in structural steel. Fatigue crack propagation results included the comparison between the base materials and weldment; these results are analyzed according to Paris equation. Figure (4) represents comparison curves of fatigue crack length ( $a$ ) versus number of fatigue cycles ( $N$ ) for specimens (1 to 5). It was observed that only straight line was fitted to the experimental data in the base materials as shown in figure (5.19), that is agreed with results obtained by researchers [18,19]. However, in the welded and heated specimens, data were fitted with more than one straight line. It is well known that, welding produces a large residual tensile and compressive stresses, compression residual stresses are established in the base during welding process residual stresses was introduced into the base metal and also resulted in the transferring to the weld metal, so that they will alter the rate of fatigue crack propagation. [3] The residual stresses formed at the weldment resulted from the weld metal contraction when it started to solidification and then continue cooling up to reach the room temperature. metal (BM).[4]

#### 4. CONCLUSION

The maximum rate of fatigue crack propagation noticed in specimen of weld distance of ( $x=20$  mm), that because of the formation of high compressive longitudinal residual stresses at the head of crack direction which resulted in arresting crack progress. So that it can be confirmed, any Increasing the distance ( $X$ ) could improving fatigue life by increasing the number of fatigue cycles to failure.

#### 5. REFERENCES

- [1] Ezzet Hameed Abdulsalam, Dijlah Journal of Engineering Science (DJES), Vol. 2, No. 3, Aug., 2025, pp. 52-561-Paris P, Erdogan F, transactions of ASME, pp (528-543), 1963.
- [2] Richard W. Neu, Andrea Spagnoli, Fatigue & Fracture of Engineering Materials & Structures: Volume 49, Issue 2, Pages: 321-662, February 2026.
- [3] Haohui Xin, José A.F.O. Correi, International Journal of Fatigue, Volume 147, June 2021, 106175.
- [4] Chang J B , American Society for Metal Structure and Failure Secssions, pp. (35-54), 1980.
- [5] Liljedahi C D M, Int. J of Fatigue, pp. (735-743), 32, 2010.
- [6] D.M. NetoD.M. NetoMicael F. BorgesEdmundo SérgioEdmundo Sérgio, Materials 2022, 15, 2156. <https://doi.org/10.3390/ma15062156>
- [7] Gaurav Kumar, Tanmay K. Bhandarkar, Sumit Ghosh, Metallurgical and Materials Transactions A, Volume 56, pages 3866–3880, (2025).
- [8] Darmadi D B, School of Mechanical Materials and Mechatronic Engineering, PhD thesis, University of Wollongong, 2014.
- [9] Monisha Manjunatha, Yevgen Gorash, Tugrul Comlekci, Applied Sciences, 2026, 16(4), 1737; <https://doi.org/10.3390/app16041737>
- [10]Ezzet Hameed Abdulsalam, Dijlah Journal of Engineering Science (DJES), Vol. 2, No. 2, Jun., 2025, pp. 171-175
- [11] Bebhini M, Engineering Fracture Mechanics, V36, No.3, pp (379-387), 1990.
- [12] Rendler N J, Experimental mechanics, pp.(557-586), Dec. 1966
- [13] Flaman M Y, Experimental mechanics, pp (205-207), Sep. 1985
- [14] Itoh Y Z, Engineering Fracture Mechanics, V33, No.3, pp (397-409), 1989.
- [15] Bighini M, Engineering Fracture Mechanics, V36, No.3, pp (379-387), 1990.
- [16] Rading G O, Welding Research Supplement, pp (307-311), July, 1993.
- [17] Zheng X, Handbook of Fatigue Crack Propagation in Metallic Structure, pp (363-395), 1994.
- [18] Zheng X, Engineering Fracture Mechanics, V18, No.5, pp (965-973), 1983.
- [19] James L A, Transactions of ASME, V101, pp (34-40), 1985.
- [20] Suzuki H, Metallurgical Transaction A, V10A, pp (475-481), April, 1979.
- [21] Chow C L, Engineering Fracture Mechanics, V24, No.2, pp (233-241), 1986.
- [22] Abdulsalam E H, Fatigue Crack Propagation in mild steel, PhD Thesis, University of Salford, UK, 1991.