Formation of Compressive Residual Stresses by Shot Peening for Spot Welded Stainless Steel Plates

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ABSTRACT

In this paper, a stainless steel 316 was selected for this study and tested to obtain its chemical composition, mechanical properties and stress relieving. Then, two plates (55*55*1) mm were first joined by spot welding and later tested by X-Ray diffraction (XRD) machine to measure the tensile residual stresses formed due to thermal effect. In order to remove the tensile residual stresses, a shot peening process for these spot welded plates was made to create the compressive residual stresses which will improve the life of spot welded part during the service. The results of the x-ray diffraction tests exhibited that only compressive residual stresses formed in the shot peened spot welded plates.

Keywords: Stainless Steel; X-Ray Diffraction; Tensile and Compressive Residual Stress; Spot Welding; Shot Peening.

تقيم الاجهادات المتبقية الانضغاطية بالسفع بالكريات لصفائح الصلب المقاوم للصدأ الملحومة نقطيا"

الخلاصة

في هذا البحث , تم أختيار الصلب المقاوم للصدأ (316) لهذة الدراسة وأختباره لأيجاد تركيبه الكيميائي وخواصه الميكانيكية وأزالة الاجهاد . حيث تم اولا" لحام صفيحتين ذات أبعاد (55 x 55 x 1) ملم باللحام النقطي وبعدها أختبرت بجهاز حيود الاشعة السينية (XRD) لقياس أجهادات الشد المتبقية بسبب التأثير الحراري الناتج من عملية اللحام .
لغرض أزالة أجهادات الشد المتبقية , أجريت عملية السفع بالكريات للصفائح الملحومة بلحام النقطة لتوليد أجهادات متبقية انضغاطية والتي ستحسن من عمر الجزء الملحوم بلحام النقطة خلال استخدامه . وأظهرت

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نتائج قياس حيود الاشعة السينية تكوين الاجهادات المتبقية الانضغاطية فقط في الصفائح الملحومة نقطيا" التي تم سفعها كرويا" .

LIST OF SYMBOLS

Symbol	Description	Unit
E	Modulus of elasticity	GPa
EL	Elongation	%
I	Current	Ampere
K.E.	Kinetic energy	Joule
Q	Heat generation rate	Joule
R	Total resistance	ohm
d	Lattice space for stressed plan	A°
do	Lattice space for unstressed plan	A°
m	Mass of shot	Kg
n	Lattice plane	--
t	Time of welding	second
v	Velocity of shot	m/sec
ν	Possion ratio	--
σ res	Residual stresses	MPa
σy	Yield stress	MPa
σu	Ultimate stress	MPa
ψ	Tilt angle	degree
λ	Wave length	A°
θ	Diffraction angle	degree

INTRODUCTION

In resistance spot welding operations, the joining of two materials is carried out using the simultaneously applying heat and pressure. Due to electrical resistance, metals are heated up to the melting state during an electrode flow, where the heat (Q) may be expressed by Joules law [1]:

$$Q = RI^2t \qquad \dots\dots\dots\dots\dots\dots (1)$$

After welding, a non –uniform temperature distribution for the welded zone introduces the tensile residual stresses, it can have a dangerous effect on the material by reducing the fatigue life of metal , crack propagation , brittle fracture and stress corrosion [2-3].

Residual stresses can be measured by several methods: (1) X-Ray diffraction, (2) Hole drilling, (3) Ultrasonic, (4) Magnetic, (5) ring method and (6) Hardness studies [4,5].

Shot peening process is one of the most important methods to improve the surface mechanical properties and to increase material fatigue life. Creation of compressive residual stresses which can combat fatigue failure, allows higher stress levels, prevents stress corrosion, enhances lubrication, enables lighters design, textures surface, forms and straightens parts, closes porosity and resists fretting and galling [6].

Previously, many research works were carried out to find out the effect of using different welding parameters [7, 8] on the quality of the spot welded joints in terms of mechanical properties, especially the yield and ultimate tensile strengths and fatigue resistance of the joint. Also, various researches were achieved regarding the effect of using the shot peening process in terms of different process parameters [9, 10] to improve the surface finish of the workpart.

But, there is a little work [11, 12] related on how to eliminate or reduce the induced tensile residual stresses by employing the shot peening process in order to create compressive residual stresses to improve the fatigue strength and to extend the service life of the spot welded mechanical parts under dynamic loadings. In addition, due to the important use of stainless steel alloys in industrial engineering applications and the existence of various methods for measuring the residual stresses, therefore this aim of this paper is to form compressive residual stresses instead of the tensile ones after shot peening spot welded specimens at different welding times from stainless steel (type 316) plate and then measuring accurately the induced residual stresses by the XRD method.

THEORY

Residual stresses due to spot welding

Residual stresses are the stresses that remain in a body if all external forces or thermal gradient after the yield point were removed, they can be included in both tensile and compressive residual stresses [13, 14]. All kinds of welding processes produce tensile residual stresses causing a very dangerous effect on engineering properties, as shown in Figure (1) [15]. So, for removing the tensile residual stresses or making them compressive which is useful, a shot peening process is needed to improve and increase the engineering properties of materials [16]. The tensile or compressive residual stresses can be calculated by the following equation [15]:

$$\sigma_{res} = \frac{\mathrm{E}}{(1+\mathrm{v})(\sin\psi_1^2 - \sin\psi_2^2)} * \frac{\mathrm{d}-\mathrm{d}_0}{\mathrm{d}_0} \ldots\ldots\ldots.(2)$$

Therefore, it is necessary to use the values of ψ_1, ψ_2, d_o and d in equation (2) to calculate the value of the residual stress (σ res). At the beginning of the test, the tilt angle $\psi_1 = 0$ for the specimen at the horizontal position in the XRD machine. While the tilt angle ψ_2 which is taken (50^o) according to the access of the machine. Then, the values of the lattice space for unstressed plan (d_o) and the lattice space for stressed plan (d) can be calculated for different diffraction angles (θ_o) and (θ), respectively by using Brag`s law [10,11].

$$2d\sin\theta = \lambda n \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The resistance spot welding (RSW) configuration is shown in Figure (2). The spot welding process consists of four stages: squeeze cycle, weld cycle, hold cycle and off cycle [17].

Shot peening process

The shot peening consists of multiple repeated impacts (stream) of structural component (Target) by small particles (shot), typically made of metal with a high hardness, with velocity of (40 - 70 m/s) [16]. The impact of each particle produces an indentation (dimple) on the surface of target due to the plastic flow of material. This indentation has a larger surface area than the original surface and, cumulatively, the indentations try to produce a surface expansion (Fig.3) [18]. The elastically deformed sub-surface layers try to resist this surface expansion, including a compressive stress at the surface balanced by a tensile stresses of lower magnitude through the core of the material, as seen in Fig. (4) [19]. The compressed layer extends (0.125-0.250) mm below the surface of the peened material. The magnitude of the compressive stress is dependent upon the kinetic energy of the impacting particle, the yield strength of the target material and the hardness of the shot and the target. Two factors, mass and velocity, influence the kinetic energy of particle in the following relation [20]:

$$K.E = \frac{mv^2}{2} \qquad \ldots\ldots. (4)$$

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EXPERMENTAL WORK

Chemical composition of used material

The chemical composition test of the experimental stainless steel type 316 was achieved in Ministry of Science and Technology using the device type EDX Pocket (III) P730. The results of this test are shown in Table 1 together with the chemical content of the standard material according to the ASTM specification [21] for comparison purpose. It can be seen from this table that the chemical composition of the used alloy is in conformity to that of the standard one.

Tensile test of used material

The tensile test was conducted in the Production and Metallurgy Engineering Department, University of Technology for the experimental stainless steel type 316 using the tensile testing machine type WDW-200E. All results of this test are given in Table 2 together with the mechanical properties of the standard material according to the ASTM specification [21]. This table indicates that the mechanical properties of the used alloy in the present paper conform to those established for the standard one.

Spot welding processes

All specimens were spot welded for different times (0,26, 0.20 and 0.10 sec) using the experimental welding parameters given in Table 3 by a spot welding machine type H.A Schlatter AG Schlionen ZH shown in Fig.(5). For the purpose of the following tests, the used specimens were then classified into different groups as given in Table (4).

X-Ray diffraction tests

All X-Ray diffraction tests were performed in the Ministry of Science and Technology by a machine shown in Fig.6 with a supplied voltage of (40KV) and current (20MA) for all specimens classified into groups in Table 4. The target is copper with a wave length (λ=1.5406 A°) and the filter is nickel. The lattice space (d) was calculated for different values of θ and n =1 by Brag's Law (equation 2) [10, 11]:

All data of the XRD tests are shown in Table 5, and by using equation (2), the residual strains and stresses obtained from XRD tests for all specimens are given in Table (6).

Shot peening processes

The shot peening process was accomplished in Institute of Technology, by Sintokogio LTD machine shown in Fig.7. A random jet of shots were subjected to all faces of plates at a medium speed of (70 m/s) with Carbon Steel shots, medium intensity, (80-100) % coverage and shot diameter of (2 mm) for 30 minutes. After that, the X-Ray test induced a different lattice space, which will change the residual stresses to compressive ones.

RESULTS AND DISCUSSION

After conducting the spot welding of stainless steel type 316, the welded specimens were experimentally prepared, and the residual stresses were measured using the XRD method. It was found that these stresses are tensile residual stresses induced from the spot welding process (for group C, D and E as shown in Table 6). And, theses stresses have a negative effect by reducing the service life of the different mechanical parts, such as the material used in this research. The reason for inducing these tensile residual stresses is due to the thermal effect particularly, leading to changes in the metallurgical structure of the material and formation of thermal strains that contribute to the formation of these tensile residual stresses.

In order to eliminate these tensile residual stresses, a shot peening process was used on the as mentioned spot welded specimens to create compressive residual stresses instead of tensile ones, where the multiple repeated impacts of the shots (balls) on the specimen surface work to deform the surface plastically and compress it due to the compressive forces from the shots impacting the surface. And, this initiates the compressive residual stresses at the surface. Consequently, the shot peening method extends the service life of the part by avoiding the growth of induced cracks that exist in the spot welded parts under dynamic loadings. These stresses were experimentally measured by the XRD method and found to be of compressive type (for group F, G and G as shown in Table 6).

CONCLUSIONS

1. The generated heat from spot welding process led to induce tensile residual stresses in the material, and these stresses help to grow the initiated cracks due to dynamic loadings, thus reducing the service life of the spot welded part.

2. The shot peening process for the spot welded part led to form compressive residual stresses that assist to avoid the growth of the cracks that exist at the surface and caused by the dynamic loadings, thus extending the working life of the part.

3. The method used for measuring the residual stresses in this research is the XRD method which is a nondestructive test method was found a suitable method that gives good results in measuring either tensile or compressive residual stresses.

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Table (1) The chemical composition of stainless steel type 316 in weight percentage (wt%).

Alloy	Mn %	Cr%	Ni%	Mo%	Fe%	C%
Standard	1-2	16-18	10-14	1-2	69-71	0.08-0.01
Experimental	1.05	15.608	12.212	1.15	70.01	0.08

Table (2) Mechanical properties of stainless steel type 316.

Alloy	σy (MPa)	σu (MPa)	EL%
Standard	≥ 290	≥ 515	≥ 38.3

Experimental	298	520	40		
Test No.	**Current (KA)**	**Welding time (sec)**	**Holding time (sec)**	**Electrode diameter (mm)**	**Electrode pressure (bar)**
1	**10.450**	**0.26**	**0.06**	**6**	**4.4**
2	**10.450**	**0.2**	**0.06**	**6**	**4.4**
3	**10.450**	**0.1**	**0.06**	**6**	**4.4**

Table (3) Experimental welding parameters.

Table (4) Groups of used specimens.

Group	Type of Process
A	**As received**
B	**After heat treatment (stress relief)**
C	**First spot with welding time (0.26 sec)**
D	**Second spot with welding time (0.2 sec)**
E	**Third spot with welding time (0.1 sec)**
F	**First spot after shot peening**
G	**Second spot after shot peening**
H	**Third spot after shot peening**

Table (5) The data of X-ray diffraction tests.

Group	d_o (A°)	θ_o (degree)	d (A°)	θ (degree)
A	0.80299	73.59506	0.80314	73.5587
B	0.80299	73.59506	0.80301	73.5902
C	0.80299	73.59506	0.80397	73.3594
D	0.80299	73.59506	0.80391	73.3738
E	0.80299	73.59506	0.80399	73.3547
F	0.80299	73.59506	0.80217	73.7951
G	0.80299	73.59506	0.80197	73.8444
H	0.80299	73.59506	0.80207	73.8197

Table (6) Residual strains and stresses obtained from XRD tests.

Group	Residual strain	Residual stress (MPa)
A	$1.86801*10^{-4}$	48.97
B	$2.490691*10^{-5}$	6.52
C	$12.20438*10^{-4}$	320
D	$11.45717*10^{-4}$	300.4
E	$12.95159*10^{-4}$	326.5
F	$-10.21183*10^{-4}$	- 267.72
G	$-12.70252*10^{-4}$	- 333
H	$-11.45717*10^{-4}$	- 300

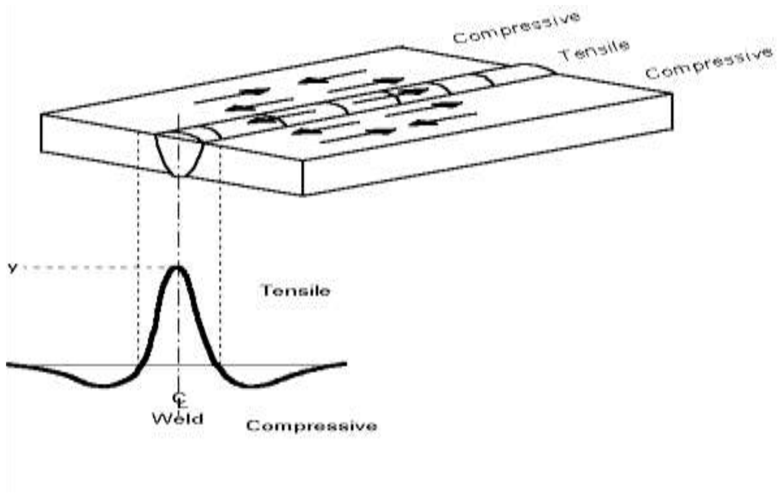

Figure (1) Distribution of the residual stresses after welding [15].

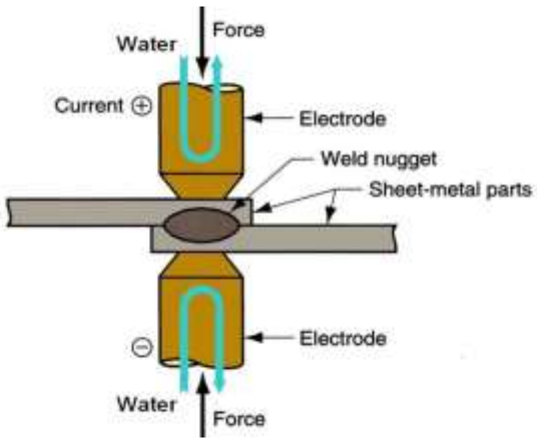

Figure (2) RSW configuration [17].

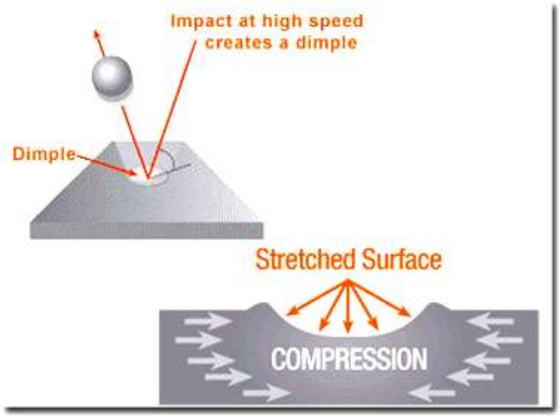

Figure (3) The surface after shot peening [18].

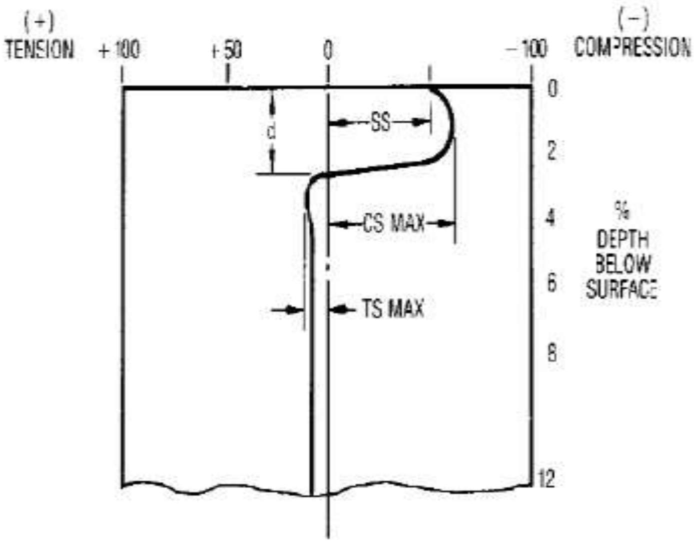

Figure (4) Residual strees after shot peening [19}.

Figure (5) Spot Welding Machine.

Figure (6) X-Ray Diffraction Machine.

Figure (7) Shot Meening Machine.