Elektrik Direnç Nokta Kaynağında Temas Direncinin Etüdü

Study Of Contact Resistance In Electirical Resistance Spot Welding

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In this study the main cause of heat development and weld nugget formation in resistance spot welding were investigated. In order to find the effect of the contact surface and of the contact resistance, weld strength which was obtained under various electrode loads and welding times was used as a criterion. The results of this study showed that the surface roughness has a great effect on the weld properties. In addition, optimum surface roughness values and the effect of electrode load on the weld properties are discussed.

Bu çalışmada, direnç nokta kaynağında ısı gelişiminin ve kaynak dikişi oluşumunun ana nedenleri araştırılmıştır. Temas yüzeyinin ve temas direncinin etkilerinin tayini için, çeşitli elektrod yüklerinde ve kaynak zamanlarında elde edilmiş, kaynak mukavemeti esas alınmıştır.

Sonuçta yüzey pürüzlüğünün kaynak özelliklerini büyük ölçüde etkilediği bulunmuştur. Ayrıca, kaynak açısından en uygun yüzey pürüzlük değerleri ve elektrod yükünün kaynak özelliklerine etkisi tartışılmıştı.r

INTRODUCTION

It has long been known that contact resistance between two metallic surfaces disappears at much less than 1 cycle after start of welding (1).

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For this reason, a number of investigations has been done to find whether contact resistance has a considerable effect on heat generation or not. Some authors (2) concluded that contact resistance has no considerable effect on heat generation and weld nugget formation during welding. According to the others (3), in very short time in which contact resistance is very high and effective, heating is concentrated only in the contact region and cause the specific resistance to be the highest in this region. According to APPS (4), although the contact resistances are effective at the start of heating, the efficiency of heat conduction away from the workpieces into the electrodes is more important than the contact resistance in determining heat build-up and the time required to from a molten weld nugget of a given volume. SATOH (5), using two-dimentional models, showed that the sheet separation which occurs before the start of heating or immediately afterwards, restricts the current path so that the heat generation occurs effectively in the region adjacent to the contact surface between specimens. In addition, he concluded that the heat which is generated by the current through contact resistance during a very short time in which contact resistance vanishes is not so significant compared with the heat generated by bulk resistance, but the contact surface condition between the specimens, even after contact resistance has disappeared, is an effective cause of heat generation: If there are only a few points of break-down of oxide film on the contact surface, the current density through these points becomes extremely high, and then welding results are determined by growth of these heat nuclei on the contact surface. If the number of current paths caused by broken down oxide film become too many, or too large current paths are formed, the current density for one current path decreases and the heat does not accumulate.

In this investigation undertaken both to find whether the contact resistance has a considerable effect on heat generation or not and to compare SATOH's conclusions with the results which are found employing real welding conditions, low carbon steel sheets of 3 mm thickness were used. The sheets were roughened with the methods met in practice (Table 2), so that the varying number of contacting spots were obtained on the surface between the sheets. In order to find the effect of the contact surface and of the contact resistance, weld strength which was obtained under various electrode loads and welding times was used as a criterion.

EXPERIMENTAL

1.0.0. — Material

Specimens used in the experiments are low carbon steel plates, 3 mm in thickness, whose chemical analysis and mechanical properties are shown in Table 1 and the dimensions of the weldments in Figure 1.

Table 1. Chemical analysis and mechanical properties of the specimens.

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Cu (%)	σ_u (N/mm²)	σ_y (N/mm²)	δ (%)	HB (N/mm²)
0.15	0.4	0.015	0.030	0.050	0.2	360	210	35	1100

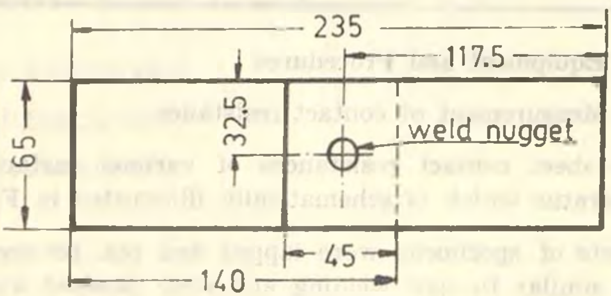


Figure 1. Dimensions of the weldments.

1.1.0. — Surface treatments of the specimens

The surfaces of the specimens were treated in three different ways:

a) Chemical method : The specimens were pickled in 5 % H_2SO_4 solution at 80°C after degreasing (6), (7).

b) Seratch brushing : Some of the specimens which were formerly treated chemically were scratch brushed on a single face with a brush of stainless steel wire of 0,5 mm diameter.

c) Grinding : Some of the specimens which were formerly treated chemically were ground on one surface.

Including the non-treated sheets four different surfaces were used in the experiments. Table 2 gives the surface roughness values of the treated and non-treated sheets.

Table 2. Surface roughness values.

Surface Treatment	Surface Roughness (microns)
Chemical Method	5.0–6.5
Scratch Brushing	4.0–5.5
Grinding	1.5–2.0
Non-treated	0.75–1.0

2.0.0. — Equipment and Procedures

2.1.0. — Measurement of contact resistance

Sheet to sheet contact resistances of various surfaces measured with the apparatus which is schematically illustrated in Figure 2.

Two sheets of specimens were lapped and put between electrodes in a manner similar to spot welding and were pressed with a certain force. Then a current flow from one electrode to the other was applied through the specimens. The current values used in the measurements were between 10 and 25 amperes d.c. Potential differences between the point A and B (Figure 2) were measured with a milivoltmeter and the current values with an ammeter. Contact resistance between the sheets was then calculated using Ohm's law.

2.2.0. — **Welding Process**

The welder employed for experiments was 150 kVA rated, electronic current and time controlled, single-phase a.c. spot welding machine and truncated-cone type special copper alloy electrodes 8,5 mm in tip diameter were used. Figure 3 shows the welding cycle followed in the experiments.

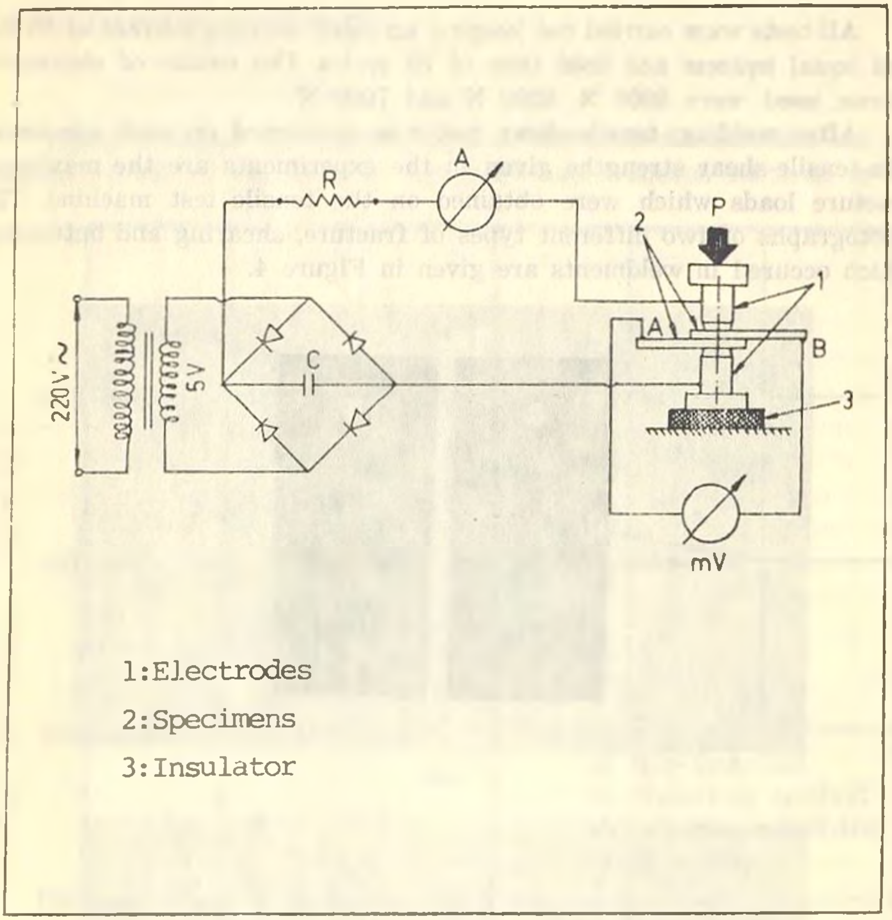


Figure 2. Measuring of contact resistance.

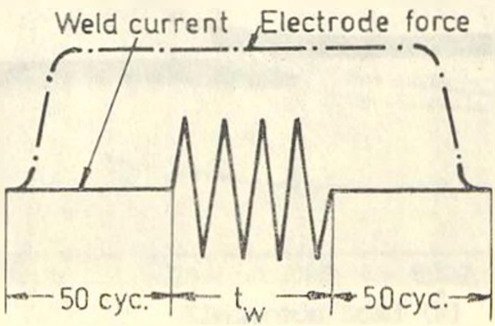
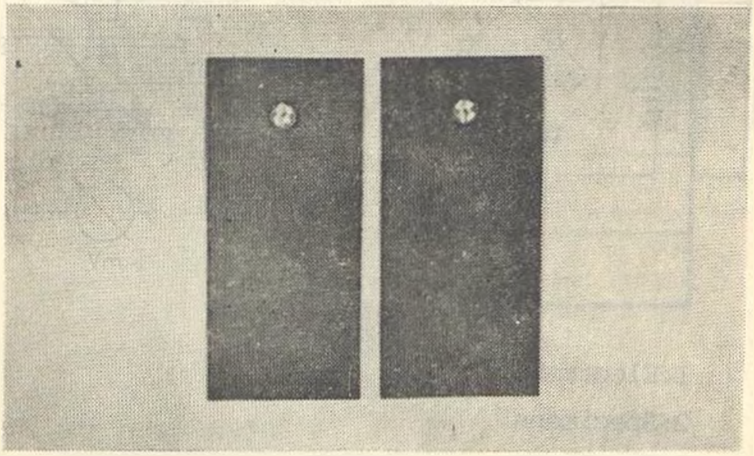


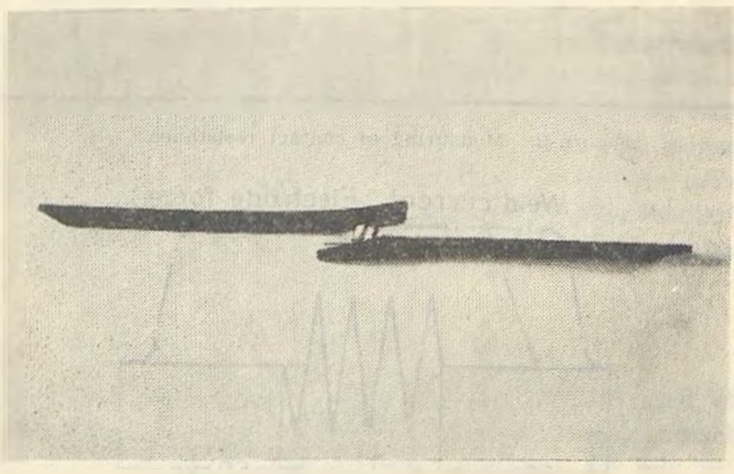
Figure 3. Schematic diagram of welding sequence (tw: weld time)

All tests were carried out keeping an equal welding current of 16 kA and equal squeeze and hold time of 50 cycles. The values of electrodes forces, used, were 3000 N, 4500 N and 7000 N.

After welding, tensile-shear test was conducted on each specimen. The tensile-shear strengths given in the experiments are the maximum fracture loads which were obtained on the tensile test machine. The photographs of two different types of fracture, shearing and buttoning, which occured in weldments are given in Figure 4.



(a)



(b)

Figure 4. The photographs of different types of fracture in the tension-shear test. (a) Shearing, (b) Buttoning

RESULTS AND DISCUSSION

a) Contact resistances

Figure 5 shows the relation between the contact resistance and the electrode load of the treated and non-treated sheets. As seen in the

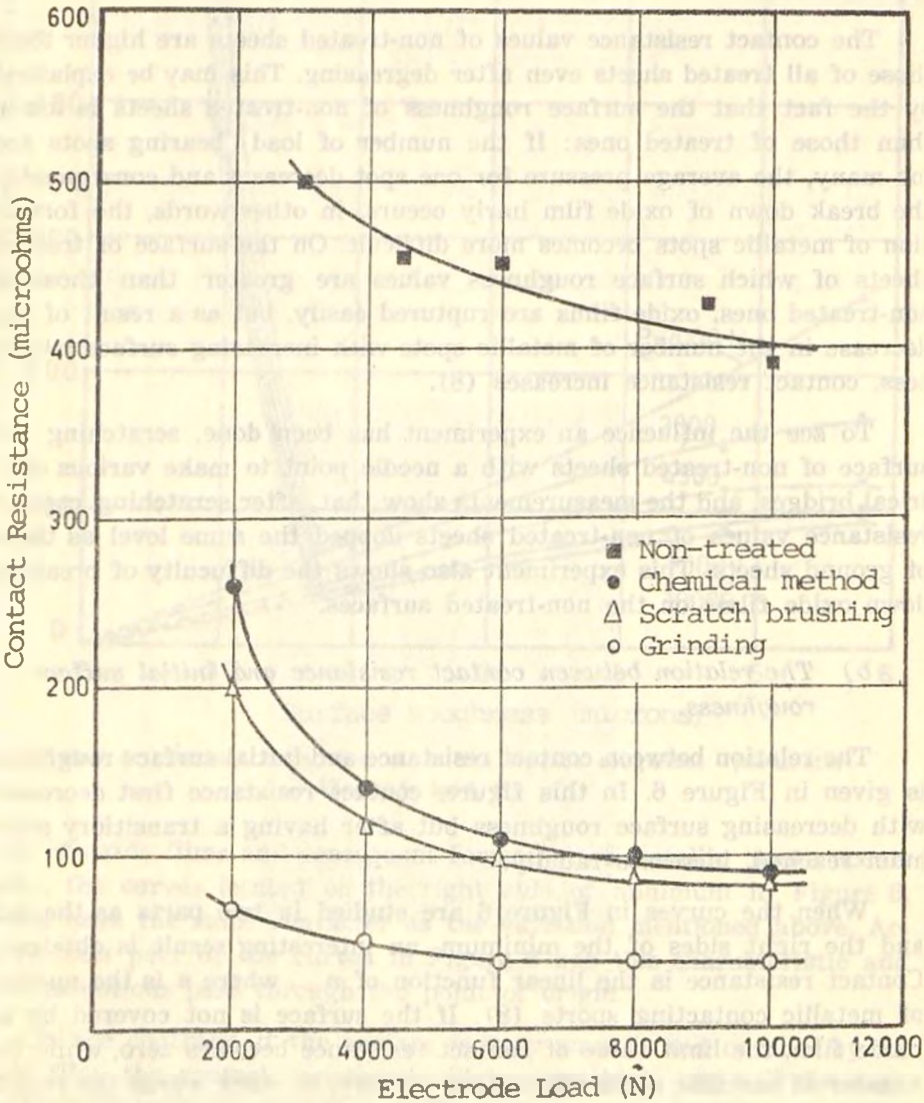


Figure 5. Contact resistance vs. electrode force

figure the contact resistance, which is high at low electrode loads, drops rapidly with the increase in the electrode load, and finally it seems to settle to a certain low value.

Among the treated sheets, the highest resistance values were obtained on the sheets treated chemically and the lowest values on the ground ones.

The contact resistance values of non-treated sheets are higher than those of all treated sheets even after degreasing. This may be explained by the fact that the surface roughness of non-treated sheets is lower than those of treated ones: If the number of load bearing spots are too many, the average pressure for one spot decreases and consequently the break down of oxide film harly occurs, in other words, the formation of metallic spots becomes more difficult. On the surface of treated sheets of which surface roughness values are greater than those of non-treated ones, oxide films are ruptured easily, but as a result of the decrease in the number of metallic spots with increasing surface roughness, contact resistance increases (8).

To see the influence an experiment has been done, scratching the surface of non-treated sheets with a needle point to make various electrical bridges, and the measurements show that, after scratching, contact resistance values of non-treated sheets dopped the same level as those of ground sheets. This experiment also shows the diffuculty of breaking down oxide films on the non-treated surfaces.

b) The relation between contact resistance and initial surface roughness.

The relation between contact resistance and initial surface roughness is given in Figure 6. In this figure, contact resistance first decreases with decreasing surface roughness but after having a transitiory minimum reached, increases rapidly.

When the curves in Figure 6 are studied in two parts as the left and the right sides of the minimum, an interesting result is obtained: Contact resistance is the linear function of n , where n is the number of metallic contacting sports (8). If the surface is not covered by an oxide film, the limit value of contact resistance becomes zero, while the number of metallic spots approaches infinity. in other words the roughness values approach to zero. Recalling that, on rough surfaces break

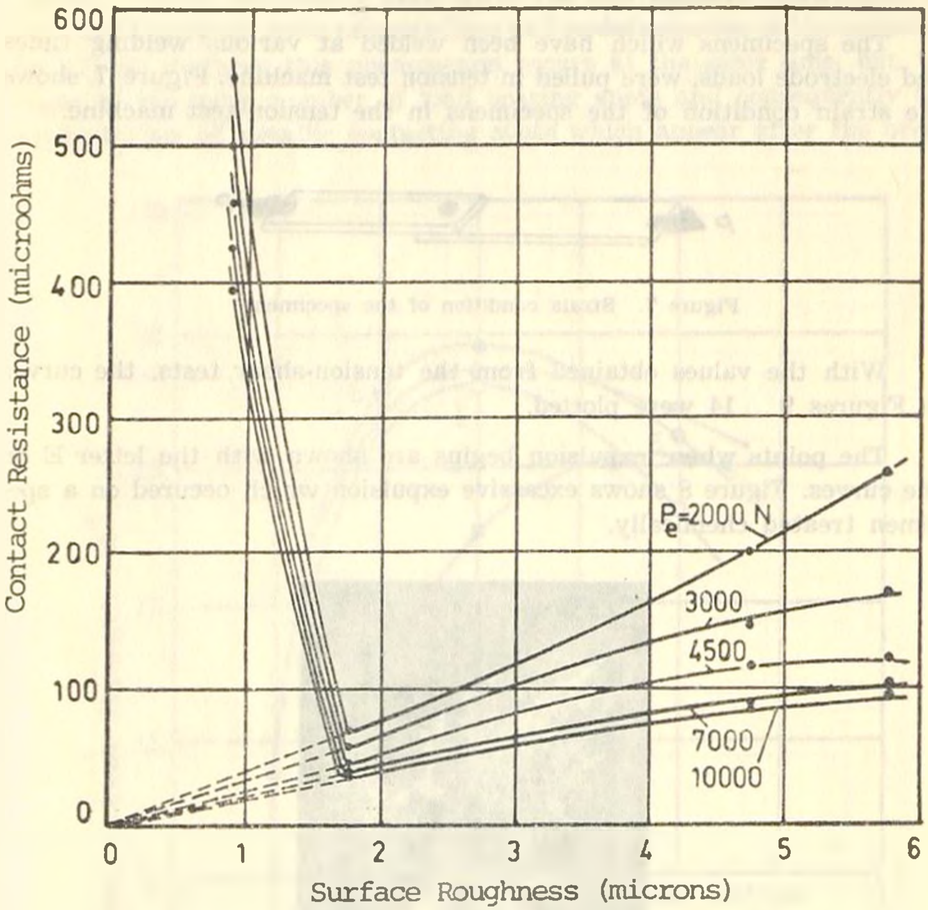


Figure 6. Contact resistance vs. initial surface roughness (parameter: Electrode load, P_e)

down of oxide films and consequent formation of metallic spots occurs easily, the curves located on the right side of minimum in Figure 6, should have the same character as the variation mentioned above. Actually, this part of the curves in Figure 6 has this characteristic and their extentions pass through the point of origin.

On the contrary, if the surface is very smooth and covered by an oxide film, the contact resistance will be very high, but will decrease rapidly with increasing roughness. This variation conforms to the variation of the curves located on the left side of the minimum in Figure 6.

c) Weld strength

The specimens which have been welded at various welding times and electrode loads, were pulled in tension test machine. Figure 7 shows the strain condition of the specimens in the tension test machine.

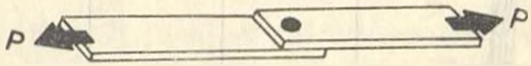


Figure 7. Strain condition of the specimens

With the values obtained from the tension-shear tests, the curves in Figures 9 ... 14 were plotted.

The points where expulsion begins are shown with the letter E on the curves. Figure 8 shows excessive expulsion which occured on a specimen treated chemically.

Figure 8. Exessive expulsion

As it may be seen in Figure 5 and Figure 9, there is not any relation between weld strength and contact resistance. But the rate of heat development and of weld nugget formation increases with increasing surface roughness. This result conforms to the conclusions given by SATOH (5). As it was mentioned previously, contact resistance disappears at much less than 1 cycle after the start of welding because of the electrical break down of oxide films and re-deformation of the spots(8). On all the surfaces this phenomenon occurs at the same time, but, because of the large number of load bearing spots and consequently the large number of metallic contacting spots which appear after the break

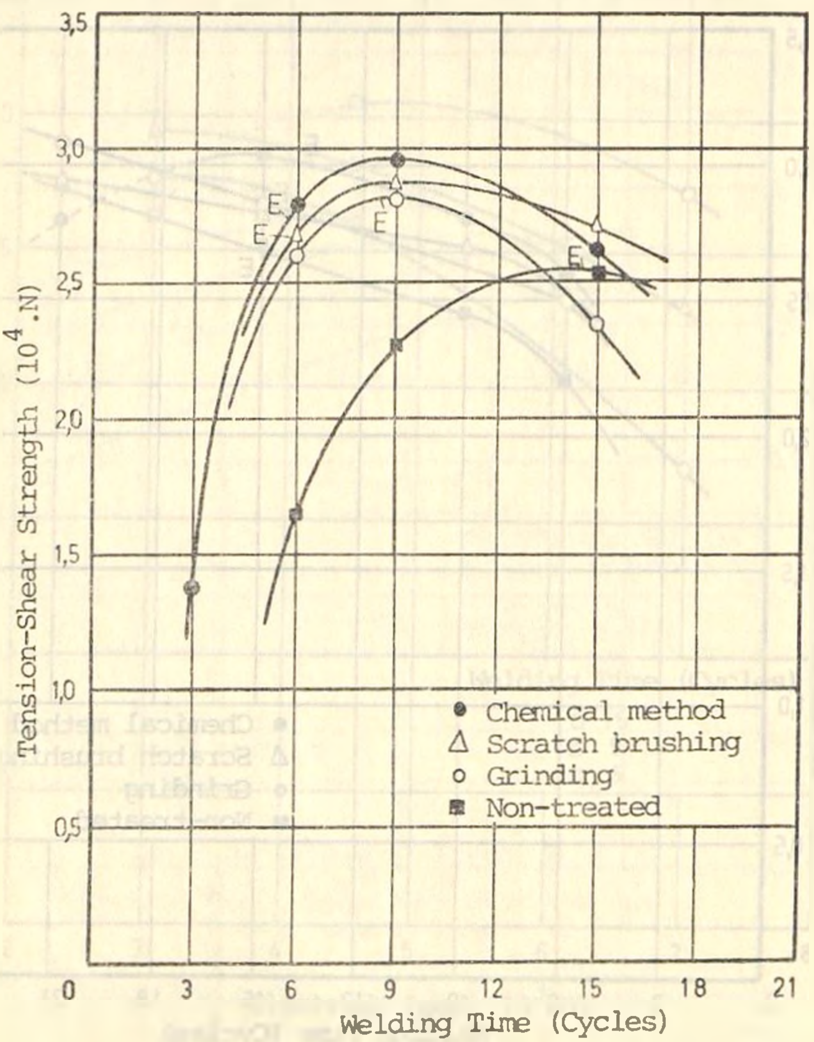


Figure 9. Tension - shear strength vs. welding time. (Electrode load, P_e = 3000 N)

down of the oxide film on smooth surfaces, the current density for one spot decreases and the rate of heat generation also decreases.

Excessive roughening cause the high heat generation rate and early expulsion (Figure 9). On the other hand, very low roughness increases the time required to obtain a certain weld strength. For this reason,

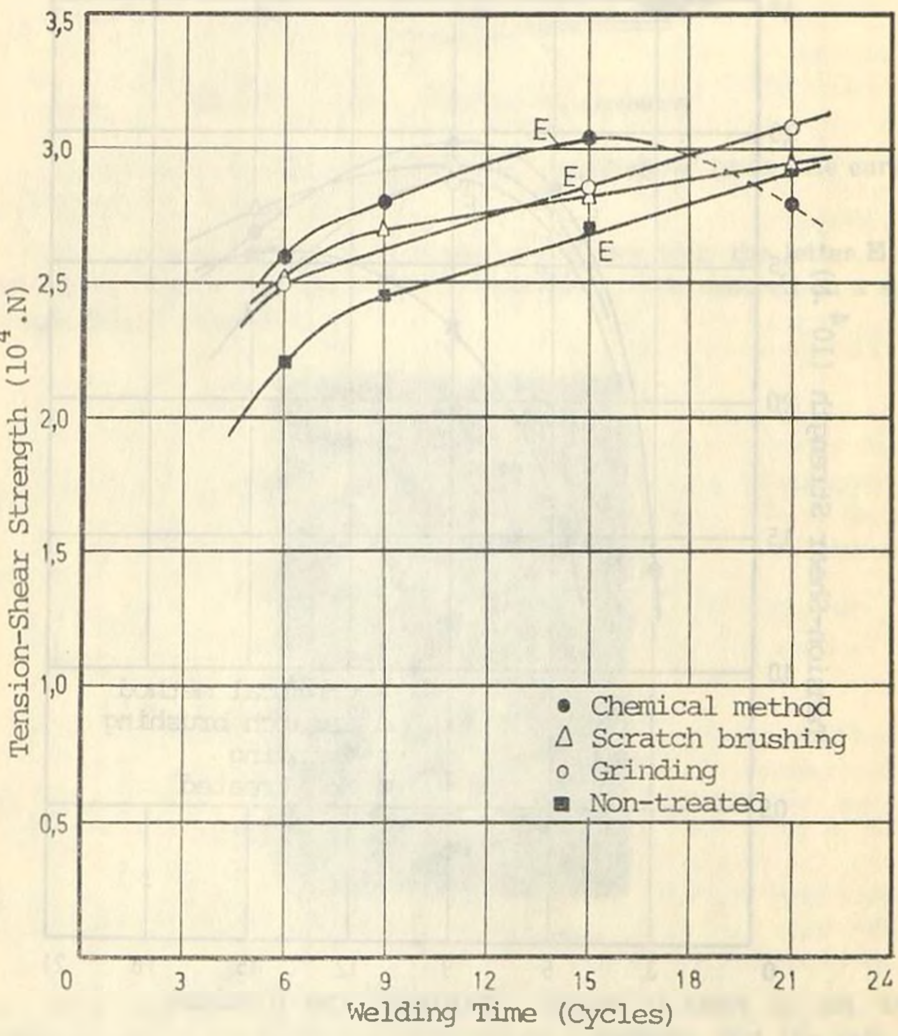


Figure 10. Tension-shear strength vs. welding time.
(Electrode load, $P_e = 4500$ N)

the surface roughness values which are on the curves situated at the right of the minimum in Figure 6, are the most suitable for welding. The upper limit of these depends on the heat transfer properties of the material concerned.

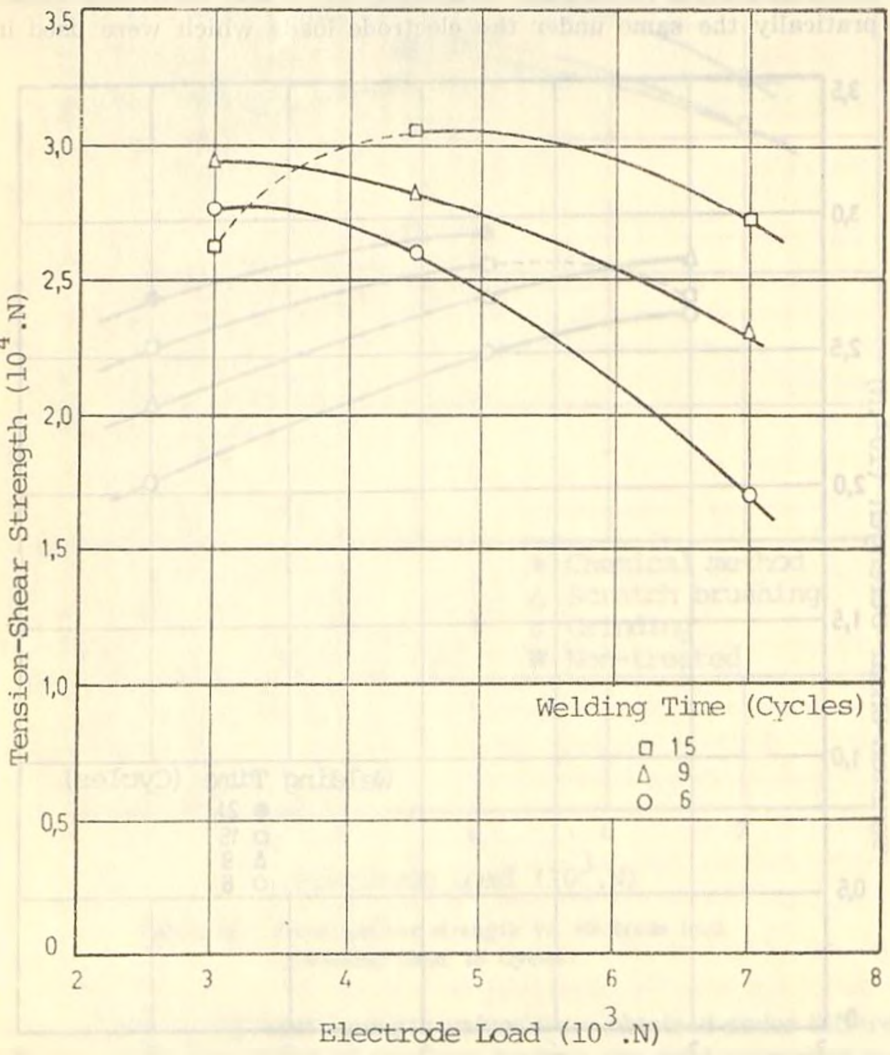


Figure 11. Tension-shear strength vs. electorde load.
(Surface treatment: Chemical method, Parameter: Welding time)

d) Effect of electrode load

Weld strength and also strength differences between the welded sheets which have different surface roughnesses, decrease with increasing electrode load (Figure 11 ... 14) This phenomenon can not be solely connected to contact resistances. Although the contact resistance values are pratically the same under the electrode loads which were used in

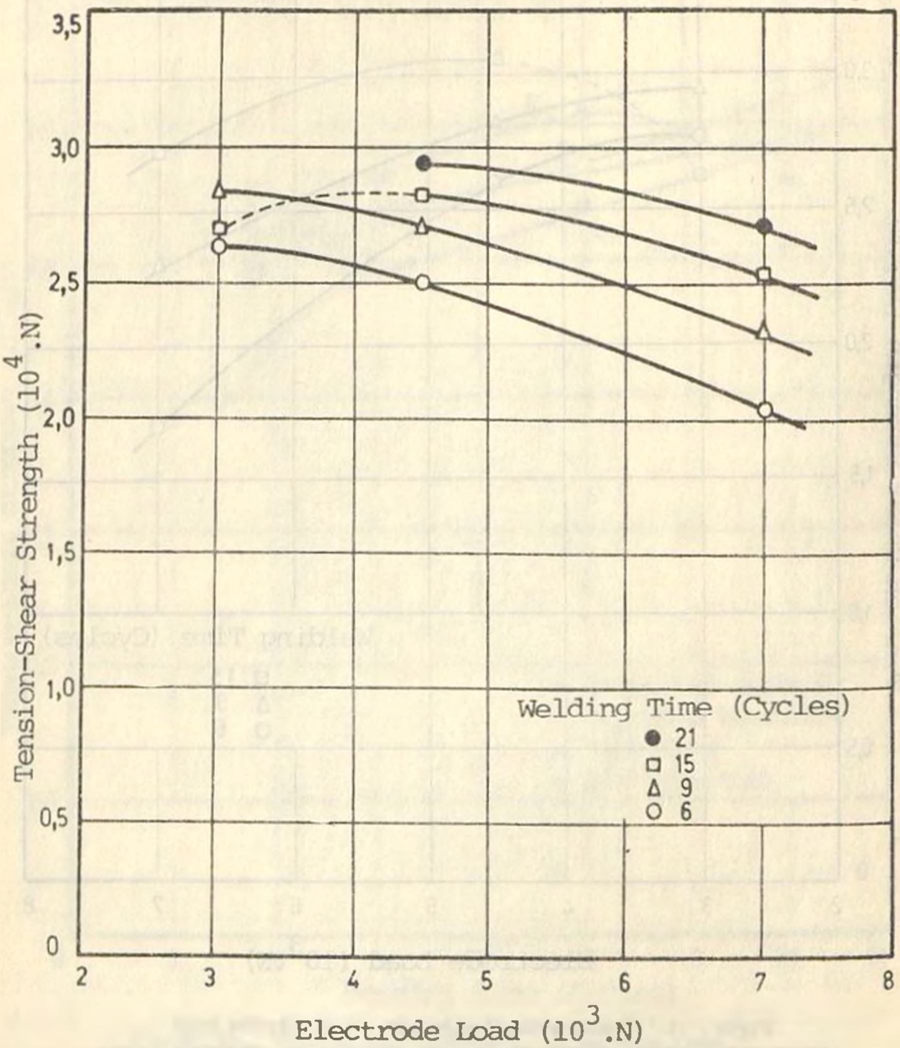


Figure 12. Tension-shear strength vs. electrode load.
(Surface treatment: Scratch brushing, Parameter: Welding time)

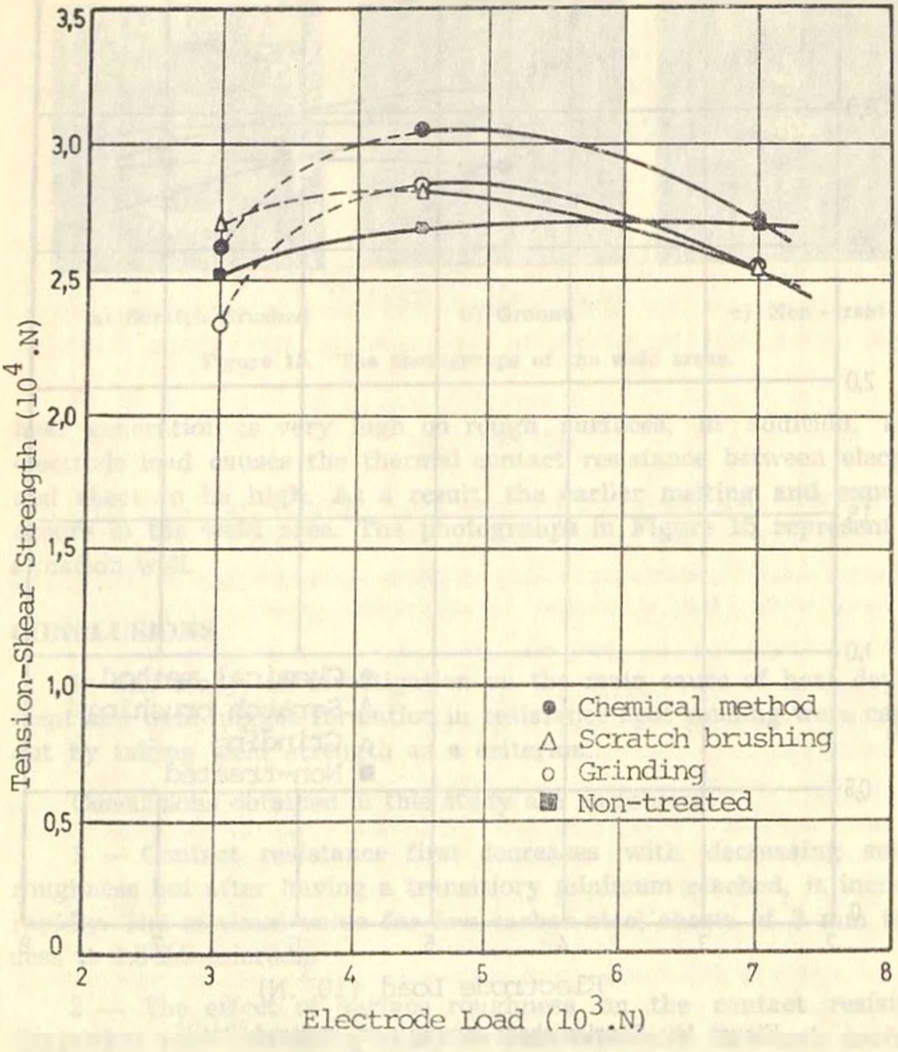


Figure 13. Tension-shear strength vs. electrode load.
(Welding time. 15 Cycles)

the experiments, different strength values were obtained under different electrode loads. The effect of electrode load on the weld properties may be explained in the following way: With increasing electrode load, the number of contacting spots and heat conduction from the workpiece into the electrodes increases. Therefore, the rate of heat generation

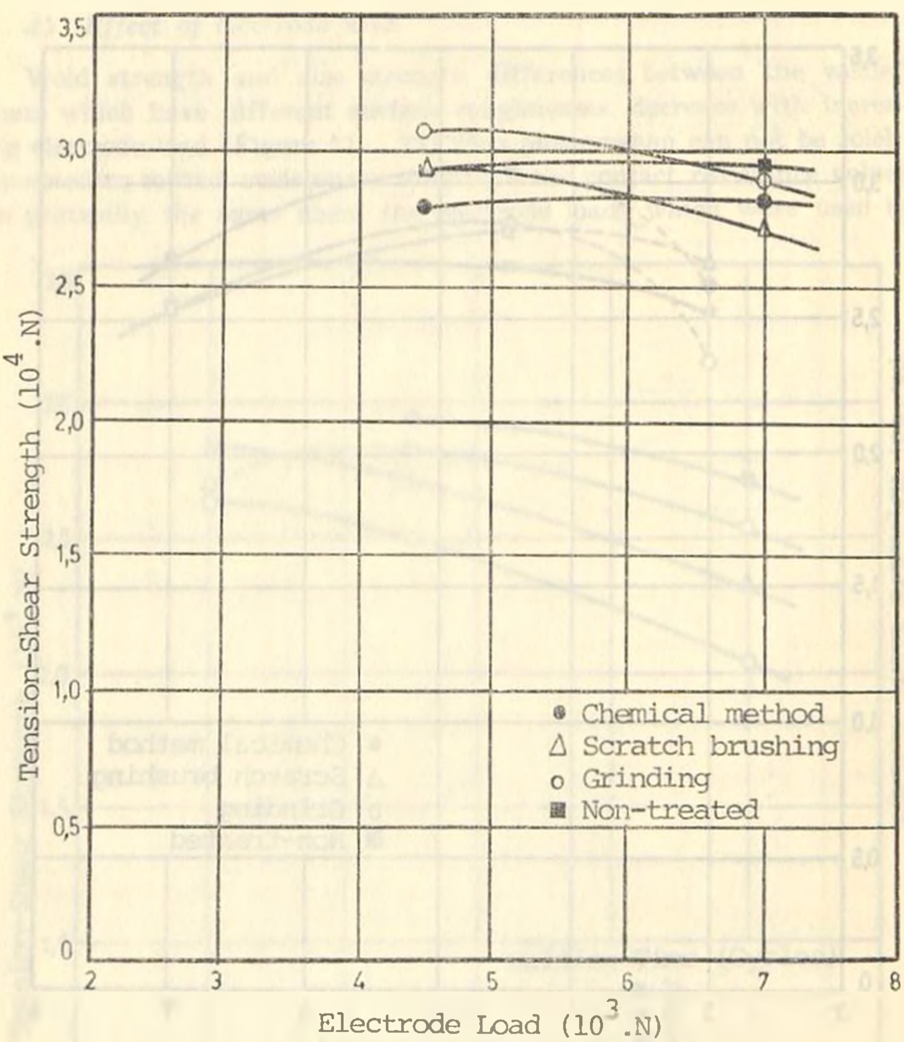


Figure 14. Tension-shear strength vs. electrode load.
(Welding time: 21 Cycles)

decreases and also the generated heat is conducted into the electrodes easily. This phenomenon lengthens the time required for the formation of the weld nugget.

The effect of the electrode load on different surfaces appears especially at low electrode loads. At the start of welding, the rate of

a) Scratch Brushed b) Ground c) Non - treated

Figure 15. The photoghraps of the weld areas.

heat generation is very high on rough surfaces, in addition, a low electrode load causes the thermal contact resistance between electrode and sheet to be high. As a result, the earlier melting and expulsion occurs in the weld area. The photograhps in Figure 15 represent this situation well.

CONCLUSIONS

In this study, an investigation on the main cause of heat development and weld nugget formation in resistance spot welding were carried out by taking weld strength as a criterion.

Conclusions obtained in this study are as follows:

1 — Contact resistance first decreases with decreasing surface roughness but after having a transitiory minimum reached, it increases rapidly. The minimal value for low carbon steel sheets of 3 mm thickness is 1,5-2,0 microns.

2 — The effect of surface roughness on the contact resistance diminishes with increasing electrode load especially on rough surfaces.

3 — There is not any relation between weld strength and contact resistance.

4 — The rate of heat generation and of weld nugget formation increases with increasing surface roughness. This result conforms to the conclusions given by SATOH (5).

5 — The surface roughness values which are at the curves on the right part of the minimum in Figure 6 are the most suitable for weld-

ing. The upper limit of the roughness value depends on the heat transfer properties of the material concerned.

6 — Strength differences between the welded sheets which have different surface roughnesses, decrease with increasing electrode load, but the time required to obtain a certain weld strength increases too.

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REFERENCES

(1) STUDER, F.J., «Contact resistance in spot welding», American Welding Journal, (1939), Vol. 18, No. 10, 374 s-380 s.

(2) DIX, A.F.J., «Metallurgical study of resistance weld nugget formation and stuck welds», Inst. of Welding Autumn Meeting, (1966), 7-13.

(3) LHEUREUX, G.E., BLOTTE, E.J., «Le Soudage par Resistance», Dunod, (1965).

(4) APPS, R.L., «Heat development and weld nugget formation in mild steel spot welds», Proceedings of the Conference on Advances in Welding Process, (April 1970), Paper 34.

(5) SATOH, T., KATAYAMA, J. ABE, H., «Temperature distribution and break down oxide layer during resistance spot welding using two-dimensional model» International Institute of Welding, (IIW-III-371-69), (1969).

(6) BAKHVALOV, G.T., TURKOVSKAYA, A.V., Corrosion and Protection of Metals», Pergamon Press, (1965), 122-123.

(7) JACKSON, M.D., «Welding Methods and Metallurgy», Grifin, (1967), 271.

(8) HOLM, R., «Electric Contacts, Theory and Application», Springer-Verlag, (1967), 21-26.