Spot Welding Characteristics of HSLA Steel for Automotive Applications

VAN-80 steel is readily spot welded using welding conditions that are compatible with existing automotive assembly line equipment and procedures

BY B. POLLARD

ABSTRACT. Resistance spot welding characteristics of a high strength low alloy steel* with carbon contents of 0.095 and 0.14% were examined and compared with low carbon steel (SAE 1008). The HSLA steel has a minimum yield strength of 80,000 psi. The effects of electrode size, electrode force, weld current and weld time were determined for 0.050, 0.075 and 0.100 in. thick material. Weld quality was assessed by means of tensile shear, cross-tension, impact shear and fatigue tests. Measurements of weld nugget diameter, fractographic and metallographic observations and hardness tests were used to correlate steel chemistry, welding conditions and weld mechanical properties.

It was found that VAN-80 steel could be readily spot welded using the same electrode size, electrode force and weld time as for low carbon steel. Due to its higher carbon and alloy content, the resistivity of the low alloy steel was higher than that of low carbon steel and lower weld currents were therefore required. Spot welds exhibited adequate ductility and, in comparison with spot welds in low carbon steel, had twice the tensile shear strength and similar impact and fatigue properties.

*VAN-80 (registered trademark), manufactured by Jones & Laughlin Steel Corporation.

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Introduction

Over the last few years, the weight of automobiles has increased considerably due to the addition of safety related items, such as impact resistant bumpers and door impact beams; emission control equipment and convenience items, such as air conditioning. At the same time fuel consumption has increased significantly, due primarily to emission control equipment. Automotive manufacturers are therefore greatly interested in reducing weight by substituting materials with a higher strength to weight ratio than low carbon steel. High strength low alloy (HSLA) steels, aluminum and plastics are all being considered, but on the basis of an optimum combination of strength and cost, HSLA steels are likely to find the widest application.

HSLA steels obtain their strength from a combination of fine grain size, solution strengthening and precipitation strengthening by means of either columbium, titanium or vanadium. These steels are produced on a hot strip mill, as a coiled product. Since no heat treatment is involved, an attractive combination of high strength, toughness, formability and weldability is obtained at a low cost.

Extensive studies, both by steel and automotive companies have shown that these steels can be readily formed into the desired shapes with only moderate changes in press-shop practice. Besides being formable, it is essential that these steels be weldable by resistance spot welding since this is the major process used on automotive assembly lines for joining sheet metal parts together. At the present time, the auto industry's production spot welding experience is, by and large, limited to low carbon steel. Since low carbon steel is readily spot welded, it is therefore the standard by which all other materials will be judged. It is reasonable to assume that the closer the welding characteristics of HSLA steels are to low carbon steel and the smaller the changes required in present welding schedules, the more readily HSLA steels will be accepted by the auto industry.

VAN-80 is a vanadium-nitrogen hot rolled steel with a minimum yield strength of 80,000 psi. This steel obtains its strength primarily from a very fine ferrite grain size (approximately ASTM No. 12), together with precipitation strengthening by vanadium carbonitride and some solid solution strengthening, primarily by silicon. Rare earth additions are used to obtain sulphide shape control, for superior formability.

Table 1 — Steel Composition, wt %

Steel	C	Mn	Si	S	P	V	N_2	Ce
VAN-80	.14	1.50	.66	.007	.007	.11	.018	.020
LC VAN-80	.095	1.16	.31	.010	.006	.096	.025	.020
SAE 1008	.078	.36	.017	.023	< .002	.015	.007	NP [(a)]

(a) NP: none present

Table 2 — Steel Tensile Properties

Steel	Y.S. ksi	U.T.S., ksi	T.E., %	U.E., %
VAN-80 (.14C)	86.6	106.9	18.5	11.5
VAN-80 (.095C)	94.1	105.4	20.6	12.7
SAE 1008	28.7	45.7	40.0	29.3

Table 3 — Steel Volume Resistivity

VAN-80 (.14C)	11.4 microhm-in.
VAN-80 (.095C)	8.8 microhm-in.
SAE 1008	5.4 microhm-in.

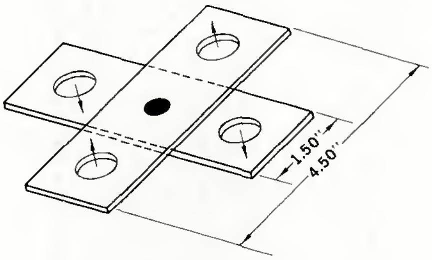

Fig. 1 — Cross-tension specimen

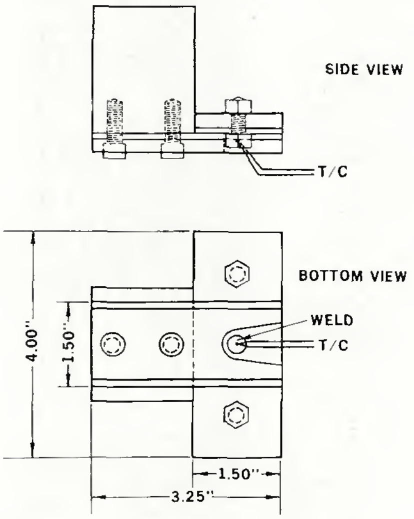

Fig. 2 — Impact shear specimen and testing jig

The spot weldability of this steel is of particular concern because the upper limit of its carbon range (0.14 %) is close to the value at which brittle martensite is formed during spot welding (Ref. 1) and postweld tempering is required. The following investigation was therefore undertaken to determine the conditions for producing strong, ductile spot welds under static, impact and cyclic loading.

Fig. 3 — Macrostructure of typical spot weld in VAN-80 Steel. Etchant: 2% Nital; X8, reduced 50%

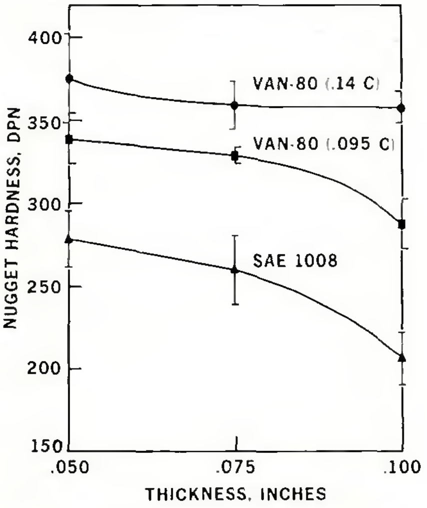

Fig. 4 — Effect of material thickness on the hardness of VAN-80 and SAE 1008 steel spot welds

Experimental Procedure

Material

The material used for this investigation was hot rolled VAN-80 steel in a pickled and levelled condition with carbon contents of 0.095 and 0.14 %. For comparative purposes, tests were also performed on hot rolled SAE 1008 steel which had been annealed, pickled and levelled. The steel compositions, tensile properties and electrical resistivities are presented in Tables 1, 2 and 3, respectively. Both the low alloy and the carbon steel were obtained in a thickness of 0.100 in., and thicknesses of 0.050 and 0.075 in. were produced by surface grinding. While the surface condition was changed, it is unlikely that the difference in surface resistivity resulting from surface grinding was greater than the scatter normally found between different materials. This approach had the advantage of providing each material in three thicknesses of exactly the same chemical composition and mechanical properties.

Welding Conditions

The major welding parameters examined were electrode size, electrode force, weld time and weld current. Preliminary tests indicated that postweld tempering was not necessary for either thickness of VAN-80 steel. Electrode size and weld time were therefore selected according to the A.W.S. recommendation for spot welding low carbon steel (Ref. 2). Welding was performed on a 150 kVA press-type machine. Since the inertia of the welding head is greater on this type of machine than with the portable guns used for auto body assembly, the squeeze time (35 cycles) and the hold time (25 cycles) were longer than would be used for production welding. The squeeze time is not critical provided that the full electrode force is applied before the welding current is switched on. Hold time can influence the rate at which the weld cools to ambient temperature and hence the nugget hardness and ductility. Under production welding conditions, hold times are typically 1 to 6 cycles (Ref. 3) compared with 25 cycles in this investigation. The results presented here are therefore conservative with respect to weld ductility.

Static Properties

Tensile shear and cross-tension tests were used to determine weld strength and ductility. The tensile shear specimens consisted of two strips of material 5.0 × 1.5 in. overlapped 1.5 in. and joined by a single spot weld. These specimens were loaded in tension parallel to the weld interface until failure occurred. The cross-tension specimens were made from 4.5 × 1.5 in. strips, oriented 90 deg to each other and joined by a single spot weld at their centers. These specimens were loaded normal to the weld interface (Fig. 1). In either test, both the failure load and the type of failure were recorded.

Dynamic Properties

Although an understanding of the properties of spot welds under static loading is essential for assessing weld quality, the load bearing capabilities of automotive structures are determined by the fatigue strengths of welds under normal service conditions and, in the event of a crash, by the ability of the welds to withstand impact loading. Thus, both impact and fatigue properties of spot welds were examined.

An impact shear test was used to measure the impact strength of spot welds. Two strips (1.5 × 3.25 in. and 1.5 × 4.0 in.) were joined together by a single spot weld to form a T-shaped specimen (Fig 2). In this test, the leg of the specimen was bolted to the hammer of a standard Charpy impact testing machine. To minimize bending, 0.25 in. thick backing plates were attached to both halves of the specimen. Since the hammer had to be removed from the machine for attachment of the specimen and cooling to the test temperature, a thermocouple was attached to the spot weld to record the temperature at the moment of impact. As the hammer swings between the anvils, one leg of the specimen is torn off on impact.

The fatigue properties of spot welds were determined using push-pull loading of tensile shear specimens. In order to determine the effects of steel composition and strength, a variety of materials was used for this part of the investigation, as indicated in Table 4. The specimens consisted of two strips of material 6 × 2 in., overlapped 2 in. and joined by a single spot weld. Testing was performed at a frequency of 1800 cycles per minute. The fatigue life was considered to have been reached when complete separation of the two halves of the specimen occurred.

Weld and Nugget Size

Under production welding conditions, weld size rather than weld strength is used as a measure of weld quality. Two measurements of weld size are possible. (1) the weld nugget diameter, and (2) the total weld diameter, i.e. the weld nugget plus the surrounding solid-state corona. Under production conditions a minimum button size, which corresponds to a high weld strength, is specified; and whether this represents the nugget or total weld size is not important. In the present investigation, both nugget and weld diameters of welds which failed through the weld interface were measured using microscopic techniques. For welds which pulled buttons of metal out of the base metal, the button diameter was measured on a shadowgraph. When a series of measurements were made using these techniques, as a function of weld current, the data were separable into two distinct curves representing nugget diameter and weld diameter.

Hardness Measurements and Metallography

Hardness measurements together with structural features were used to correlate steel composition, welding conditions and weld properties. Transverse sections through the center of each weld were prepared for metallographic examination and hardness measurements. Weld nugget hardness was taken as the average of five measurements made at roughly equal intervals along the weld interface while hardness measurements across the heat affected zone were performed at intervals of 0.010 in.

Results and Discussion

Weld Nugget Hardness and Microstructure

The macrostructures of VAN-80 spot welds were not noticeably different from those in low carbon steel (Fig. 3). Hardness measurements, on the other hand, revealed a significant difference. For full size spot welds in SAE 1008 steel, nugget hardness decreased from 262-296 DPN for 0.050 in. thick material down to 190-220 DPN for 0.100 in. thick material (Fig. 4). In contrast, the hardness of spot welds in VAN-80 containing 0.14% carbon was substantially higher (349-403 DPN) and only slightly dependent on material thickness. The lower carbon VAN-80 weld nuggets were, as to be expected, intermediate in hardness between the higher carbon and SAE 1008. For all materials, the hardness decreased slightly with nugget size, i.e. with weld heat input.

Detailed structural examination revealed that the VAN-80 weld nuggets with a hardness of 400 DPN were 100% martensitic, whereas those with a hardness of 360 DPN contained a small amount of bainite (Fig. 5a). The low carbon VAN-80 (Fig. 5b) and SAE 1008 weld nuggets with a hardness above 250 DPN were a mixture of roughly equal amounts of martensite and bainite, whereas the SAE 1008 weld nuggets with a hardness of less than 250 DPN were predominantly bainitic (Fig. 5c).

Tensile Shear Strength

Typical results for the effect of weld current on tensile shear strength for

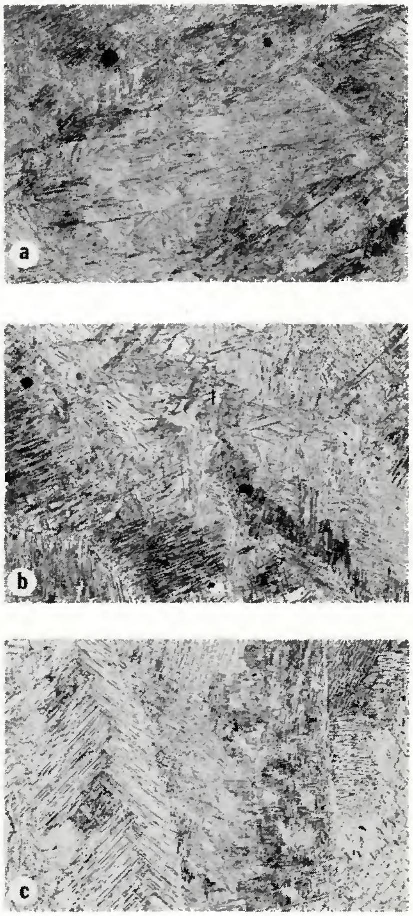

Fig. 5 — Microstructures of weld nuggets in 0.100 in. thick material. (a) VAN-80 (.14C), hardness 360 DPN, predominantly martensitic; (b) VAN-80 (.095C), hardness 293 DPN, mixture of martensite and bainite; and (c) SAE 1008, hardness 207 DPN, mainly bainitic. Etchant: 2% Nital; X500, reduced 52%

Table 4 — Compositions of Steels Used for Fatigue Specimens, wt %

Steel	Thickness, in.	C	Mn	Si	S	P	Al	V	Ti	N_2	Ce
VAN-80	.082	.14	1.24	.59	.012	.015	.067	.11	<.005	.018	.020
VAN-80	.073	.15	1.47	.42	.012	.010	.063	.12	<.005	.019	.009
LC VAN-80	.073	.08	1.21	.33	.011	.007	.013	.12	<.005	.017	.022
Ti steel (80 ksi Y.S.)	.073	.12	.50	.05	.018	.020	.030	NP [a]	.25	.005	NP
SAE 1012	.079	.13	.47	.018	.016	.006	.007	.007	.001	.004	NP
SAW 1008	.073	.09	.40	.008	.017	.007	.058	<.02	<.004	.006	NP

(a) NP: none present

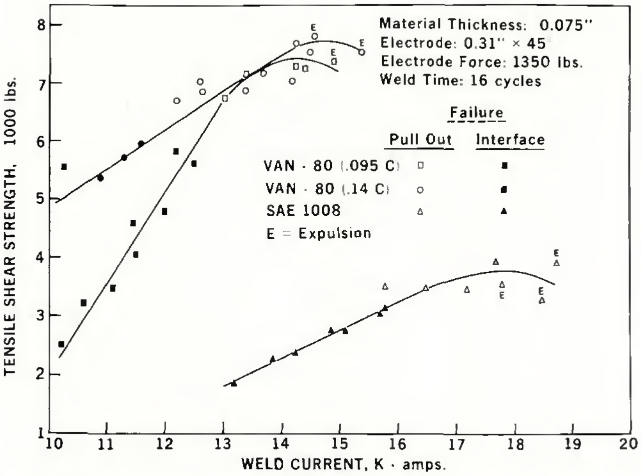

Fig. 6 — Effect of weld current on the tensile shear strength of spot welds in 0.075 in. thick VAN-80 and SAE 1008 steel

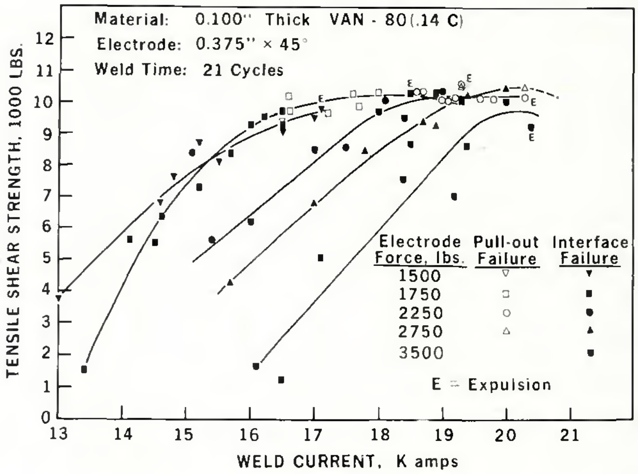

Fig. 7 — Effect of electrode force on the tensile shear strength — weld current relationship for 0.100 in. thick VAN-80 steel

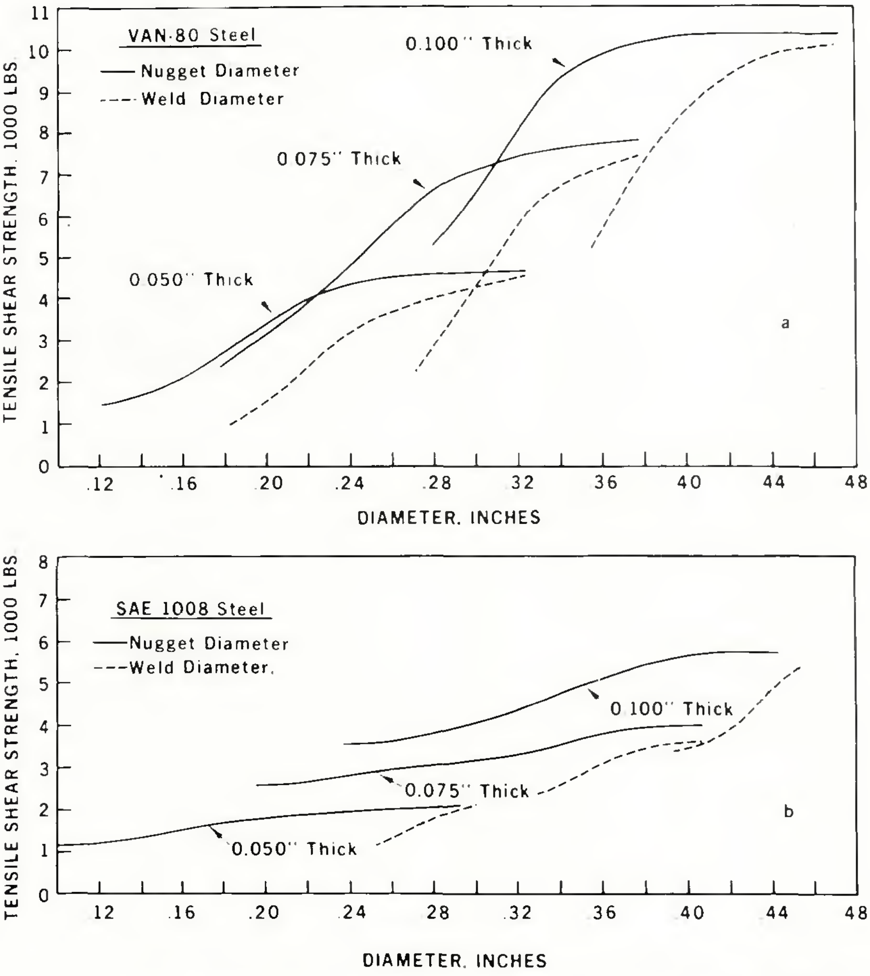

Fig. 8 — Effect of nugget and weld diameters on the tensile shear strength of VAN-80 and SAE 1008 spot welds

a fixed electrode force are presented in Fig. 6. Comparison of VAN-80 and grade 1008 steel revealed that for the same electrode force, because of higher resistivity, a lower weld current was required for the low alloy than for the 1008 steel. The range of weld current over which strong welds were produced was as large or larger than the range for grade 1008. Carbon content within the range 0.095 to 0.14 %, had only a small effect upon weld current requirements or the range of weld current over which strong welds were produced. Increasing electrode force caused the tensile shear curves to shift to higher weld currents and reduced the weld current range over which strong welds were produced (Fig. 7).

The influence of nugget and weld diameters on the tensile shear strength of VAN-80 and grade 1008 welds is shown in Fig. 8 (data points were omitted for clarity). There was negligible difference in the strength of welds of the same diameter with carbon contents of 0.095 and 0.14 %, and the weld nugget size required for maximum tensile shear strength was approximately the same for both steels. However, the strength of the low alloy steel welds was more sensitive to nugget size than the low carbon steel welds. For example, a 25 % decrease in nugget size (assuming the initial nugget size is equal to the electrode face diameter) produced a 30 to 50 % decrease in tensile shear strength for the low alloy steel welds compared with a 10 to 30 % decrease for low carbon steel welds, the lower figure in both cases applying to the 0.050 in. thick material and the higher figure to 0.100 in. thick material. As the nugget size decreased, the difference in strength between low alloy and low carbon steel welds decreased, which indicates that the contribution of the solid state corona to the weld strength was less for VAN-80 than for low carbon steel welds. Maximum tensile shear strength increased linearly with material thickness for both low alloy and low carbon steel spot welds (Fig. 9). The tensile shear strengths of VAN-80 spot welds were approximately twice those of welds in grade 1008 steel. This ratio corresponds to the ratio of the base metal ultimate tensile strengths and is not significantly affected by carbon content within the range 0.095 to 0.14 %.

Two distinct types of failure occurred in the tensile shear test (Fig. 10):

1. In the first case, failure occurred by ductile shearing through the thickness of the material, in the heat-

affected zone or base metal, so that a button of metal was pulled out.

2. In the second case, failure occurred along the weld interface.

For both steels, the first type of failure occurred only with welds with strengths in the range of the maximum values (Fig. 6). Interface failure, on the other hand, occurred for VAN-80 and grade 1008 welds with both low and high strength levels, particularly those made in 0.100 in. thick material with high electrode forces (Fig. 7). Both types of failure were observed with specimens which had suffered expulsion of weld metal due to excessive current.

While the pull-out failures were obviously ductile, examination of the fracture surfaces of the interface failures by scanning electron microscopy revealed that they also were 100 % ductile (Fig. 11). The type of failure obtained in the tensile shear test was therefore not indicative of the weld ductility and was, in fact, determined by the relative strengths of the weld nugget and base metal. Weld nugget hardness depends on the steel composition, particularly the carbon content, and the cooling rate. As the material thickness increased, larger heat inputs were required to make the weld and the weld therefore cooled more slowly to ambient temperature, resulting in softer weld nuggets (Fig. 4). Simultaneously, the through-thickness failure load of the base metal increased. Therefore, the range of weld current over which pull-out failures occurred decreased with increasing material thickness. Since spot welds in 0.095 % carbon VAN-80 were softer than those containing 0.14 % carbon, the range of weld current over which pull-out failures occurred was lower for the VAN-80 steel with the lower carbon content.

The effect of electrode force on the type of weld failure may be understood by referring to Fig. 12. Increasing electrode force resulted in an initial decrease in nugget hardness, presumably due to a higher heat input. To offset this decrease in nugget hardness the nugget diameter required to obtain a pull-out failure increased from 0.355 in. for 1500 lb to 0.395 in. for 2250 lb electrode force. No significant change in nugget hardness occurred for higher electrode forces; therefore, no further increase in nugget diameter would be required to obtain pull-out failures.

However, the maximum possible nugget size, after first increasing with electrode force to a maximum at an electrode force of 2250 lb, subsequently decreased so that the nugget diameter was too small to produce pull-out failures for electrode forces greater than 2800 lb. It should be reiterated, however, that there was no significant difference in maximum tensile shear strength of spot welds in VAN-80 containing 0.095 and 0.14 % carbon or between welds made with different electrode forces. The fact that both types of failures may be obtained for welds of the same strength merely indicates that the shear failure load of the weld nugget and the through-thickness failure load of the base metal are approximately equal. A pull-out failure therefore always indicates a good weld but an interface failure does not necessarily indicate a bad weld.

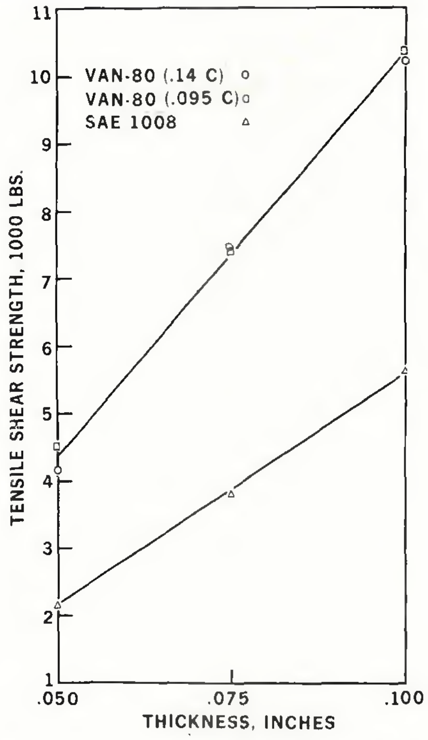

Fig. 9 — *Effect of material thickness on the tensile shear strength of spot welds in VAN-80 and SAE 1008 steel*

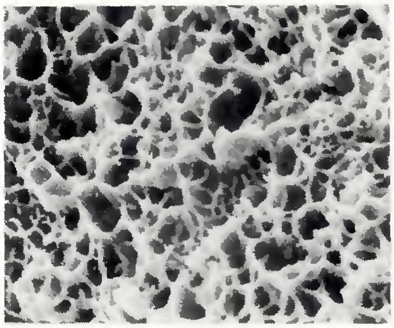

Fig. 11 — *Typical fracture surface of a VAN-80 spot weld. X5000, reduced 18%*

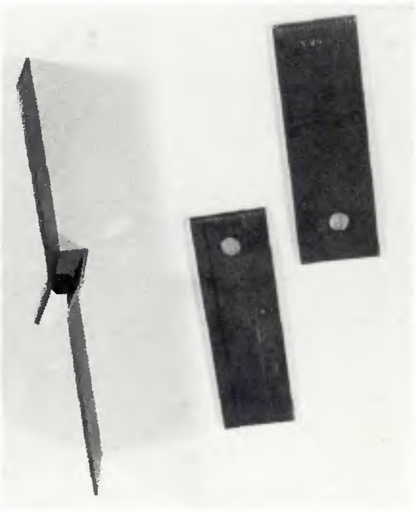

Fig. 10 — *Tensile Shear Failures, (left) pull-out failure, and (right) interface failure*

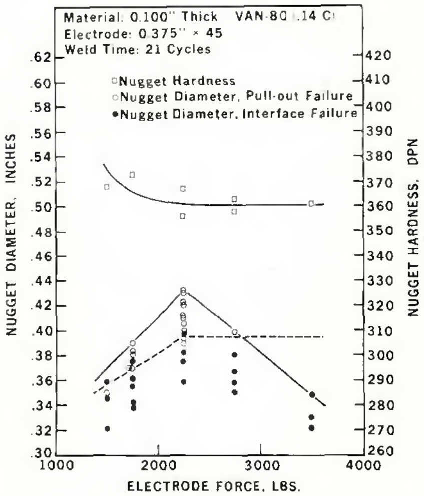

Fig. 12 — *Effect of electrode force on the maximum nugget diameter, nugget hardness and the type of failure obtained in the tensile shear test*

Cross-Tension Strength

Analysis of the cross-tension strength data (Fig. 13) revealed two distinct regions on each curve: (1) a low current region in which the cross-tension strength of the weld increased with weld current, and (2) a plateau region in which the cross-tension strength was essentially independent of weld current. In the first region the cross-tension strength was simply determined by the weld diameter; in the second region cross-tension strength was determined by weld ductility.

The maximum cross-tension strength of spot welds in VAN-80 steel was approximately 8 to 15 % higher than for welds in grade 1008, for thicknesses of 0.050 and 0.075 in., but, more important, the plateau region was much wider. For 0.100 in. thick material, where the plateau regions were similar, the maximum cross-tension strength of spot welds was slightly higher for VAN-80 containing 0.095 %C but slightly lower for that containing 0.14 %C, compared to SAE 1008. This difference was probably due to the higher carbon welds being more sensitive to the constraint of the high strength base metal in the heavier gage.

The ratio of the cross-tension strength to the tensile shear strength (The ductility ratio) is a commonly used measure of spot weld ductility. The ductility ratio for VAN-80 welds was 0.4 to 0.6 compared to values of 0.8 to 1.0 for low carbon steel welds (Fig. 14). However pull-out failures were obtained for both materials, which indicates that the ductility of the low alloy spot welds was adequate although lower than for welds in low carbon steel.

All three steels showed an increase in ductility ratio with an increase in thickness (Fig. 14), due to a decrease in nugget hardness. For VAN-80 spot welds, the steel with the lower carbon content had a slightly higher ductility ratio. The ductility ratio decreased with an increase in weld nugget hardness, as shown in Fig. 15, but the results were displaced, there being a difference of 0.2 to 0.3 in the ductility ratio between VAN-80 and grade 1008 welds with the same nugget hardness (290 DPN). The difference in ductility ratio between welds with the same hardness was undoubtedly due to the greater restraint provided by the higher strength material. Similar results would be expected for all HSLA steels.

Impact Shear Strength

While the tensile shear and cross-tension tests afford a measure of spot weld ductility under static conditions, impact tests should reflect a similar measure of ductility or toughness under dynamic loading. Impact shear strengths were similar for VAN-80 and grade 1008 spot welds, tested in the temperature range +75 F to -100 F (Fig. 16). With the exception of the welds in 0.100 in. thick grade 1008 steel, there was no abrupt decrease in impact strength with decrease in temperature, within the range of +75 F to -100 F for either material, as is generally observed with impact tests on base metals; rather, the change was gradual. For the welds in 0.100 in. thick grade 1008 steel, the impact strength decreased sharply at -90 F. The specimens used for all tests were spot welds which exhibited maximum strength and pull-out failures in a tensile shear test.

While the effect of nugget size was not examined, one could expect to find a relationship similar to that presented in Fig. 8. With the exception of welds in 0.100 in. thick SAE 1008, tested at -90 F, all failures in both steels were of the pull-out variety. For welds in 0.100 in. thick SAE 1008, tested at -90 F, failure started in the weld heat-affected zone and a brittle fracture propagated outwards through the base metal in a direction transverse to the impact direction. Although it is not possible at the present time to specify a minimum impact energy for spot welds in HSLA steels, the fact that all the VAN-80 spot welds failed by pulling out buttons indicates adequate impact strength.

Fatigue Strength

The impact properties of spot welds are only important in the event of a crash. Under normal service conditions, the serviceability of automotive structures is determined by the ability of the spot welds to withstand cyclic loading. The general shapes of the fatigue curves for spot welds were similar to the regular S-N curves for base metals (Fig. 17) but differed in having much lower fatigue ratios (the ratio of the fatigue strength at 10^7 cycles to the static shear strength of the weld). For welds in 0.082 in. thick VAN-80, the fatigue ratio was 9.9 % for a stress ratio R = +1/2, 5.6 % for R=0 and only 3.4 % for R=-1 (Fig. 17). The fatigue strengths of VAN-80 spot welds with carbon contents of 0.08 and 0.15 % are compared to an 80,000 psi yield strength Ti-steel and two low carbon steels in Fig. 18. The

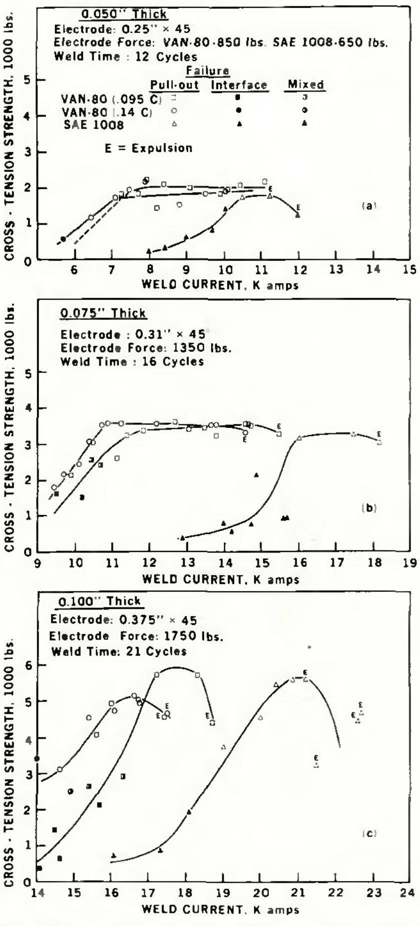

Fig. 13 — Effect of weld current on the cross-tension strength of spot welds in VAN-80 and SAE 1008 steels

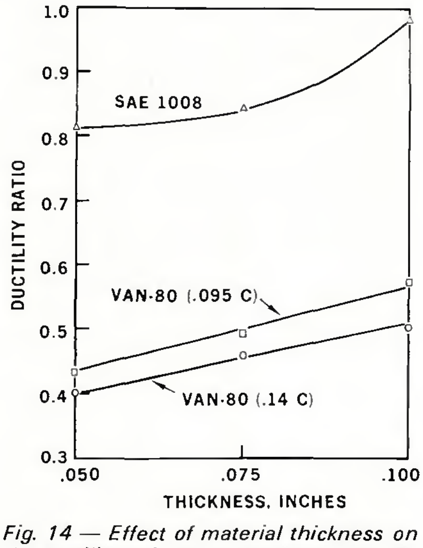

Fig. 14 — Effect of material thickness on the ductility ratio of spot welds in VAN-80 and SAE 1008 steels

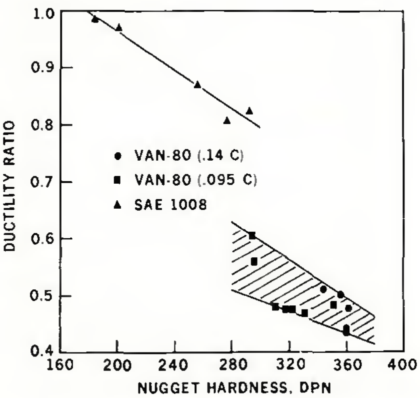

Fig. 15 — Dependence of ductility ratio on weld nugget hardness

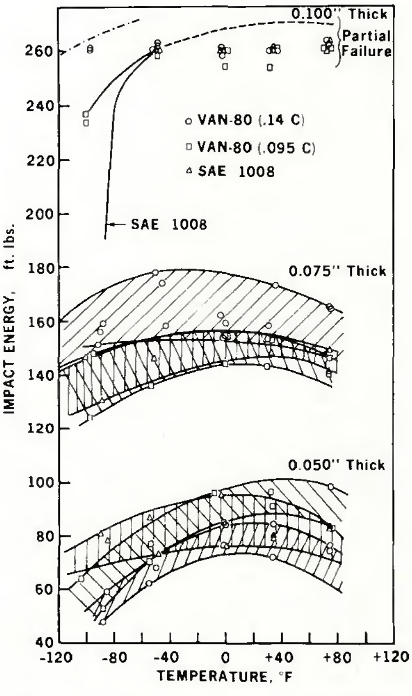

Fig. 16 — Impact shear strength of VAN-80 and SAE 1008 steel spot welds

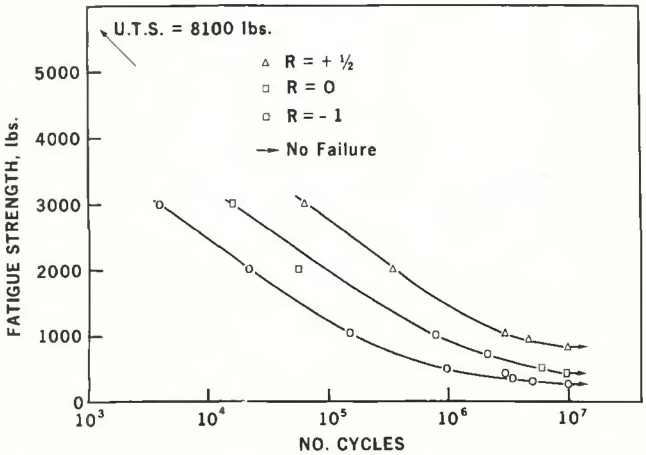

Fig. 17 — Fatigue strength of spot welds in 0.082 in. thick VAN-80(.14C)

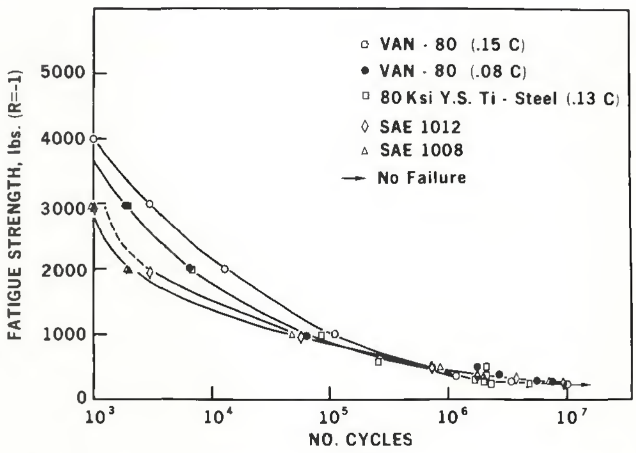

Fig. 18 — Comparison of the fatigue strengths of spot welds in 0.073 in. thick VAN-80 (.08 and .15C), Ti-steel, SAE 1012 and SAE 1008 steels

high strength steels had higher fatigue strengths for low cycle fatigue but were no better than low carbon steel for fatigue lives of 10^6 to 10^7 cycles. The spot welds in VAN-80 steel containing 0.15 % carbon were slightly stronger than those containing 0.08 % carbon for fatigue lives of less than 5×10^5 cycles but were slightly weaker for fatigue lives greater than 5×10^5 cycles. A comparison of Figs. 17 and 18 indicates that for a stress ratio, R=–1, the fatigue limit increased approximately 10 % for a 12 % increase in material thickness.

Irrespective of the material composition and thickness or the stress ratio, failure started in the HAZ of the weld at low loads and final separation occurred by the crack propagating outwards through the base metal (Fig. 19). At high loads the fatigue crack continued around the weld nugget until it separated from the base metal in a similar manner to the pull-out failures in the tensile shear test. Since for the major part of the fatigue life at low loads the fatigue crack was within the HAZ region of the weld, and at high loads failure was of the pull-out variety, the fatigue strengths were essentially independent of specimen width.

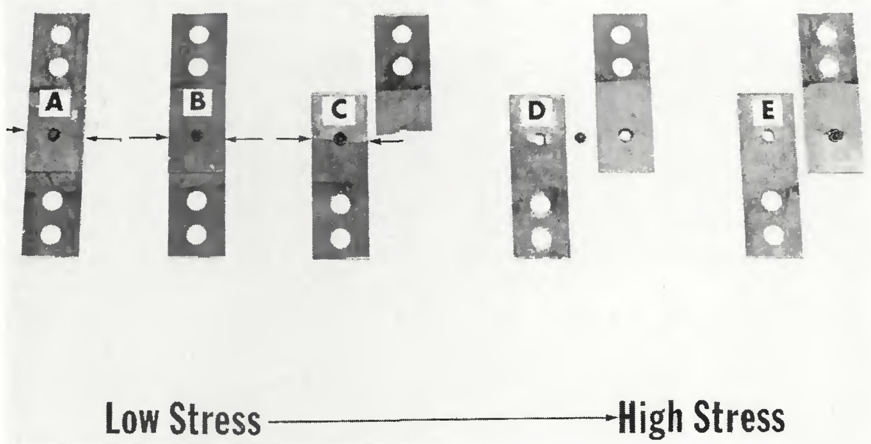

Fig. 19 — Fatigue failures. Arrows indicate failure locations on low stress specimens

Fatigue failures always started at the "notch" at the periphery of the weld (Fig. 20) which was located in the weld HAZ. Since the hardness changed greatly across the narrow HAZ region and the position of the "notch" could not be accurately determined, the mean HAZ hardness was taken as representative of the material properties at the fatigue crack initiation site. Fatigue strength increased with mean HAZ hardness for short lives but this effect decreased with increasing fatigue life (Fig. 21). For a fatigue life of 10^6 to 10^7 cycles, mean HAZ hardness had no effect on fatigue strength. Changes in welding conditions will therefore have no significant effect on the fatigue limit of spot welds. These results are consistent with the well known increase in the notch sensitivity of steels with increase in strength (Ref. 4) and emphasize the overriding effect of weld geometry in determining the fatigue properties of spot welds. Provided that the designer appreciates that the fatigue strengths of spot welds in HSLA steels are no better than similar welds in low carbon steels, this need not restrict the use of HSLA steels in automobiles since it is a simple matter to increase the number of welds in a joint.

Spot Welding Conditions for VAN-80 Steel

Recommended conditions for spot welding VAN-80 steel are presented in Table 5. Since all VAN-80 welds had adequate ductility without post-weld tempering, the criterion used in selecting these conditions was a tensile shear strength of not less than 65 % of the maximum values obtained in the tensile shear test. The type of weld failure obtained in the tensile shear test was not considered because the requirement of a pull-out failure, as used as a criterion for a good weld with a chisel or peel test, is considered too severe, particularly for the thicker material (e.g. 0.100 in.). However, welds made using the conditions recommended in Table 5 will pull buttons in the cross-tension test. In general, the lower end of the weld current range is recommended for high carbon (>0.11 %) VAN-80 steel and the upper end of the current range for low carbon (<0.11 %) steel. To overcome fit-up problems, higher electrode forces than the values listed in Table 5 may be used. Higher weld currents or longer weld times will then be necessary.

Summary and Conclusions

The results of this investigation show that VAN-80 steel can be spot welded using the same electrode size, electrode force and weld time as for low carbon steel of the same thickness. Only the weld current is different, being lower for VAN-80 than for SAE 1008 because of the former's higher resistivity. Recommended

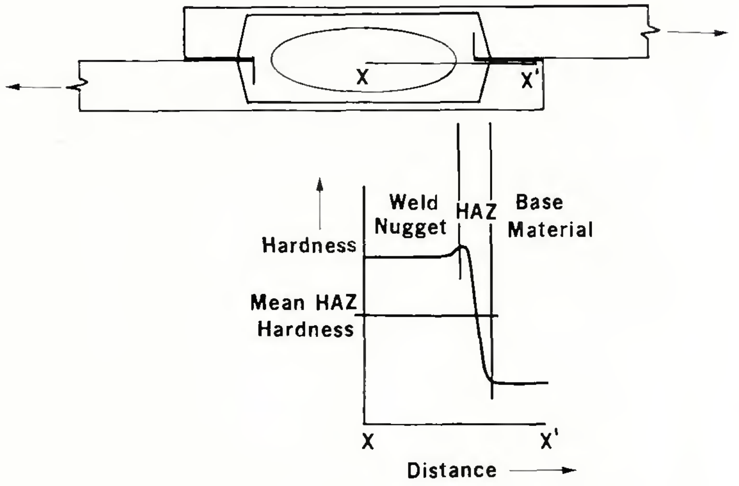

Fig. 20 — Cross-section of spot weld showing hardness profile and location of fatigue cracks

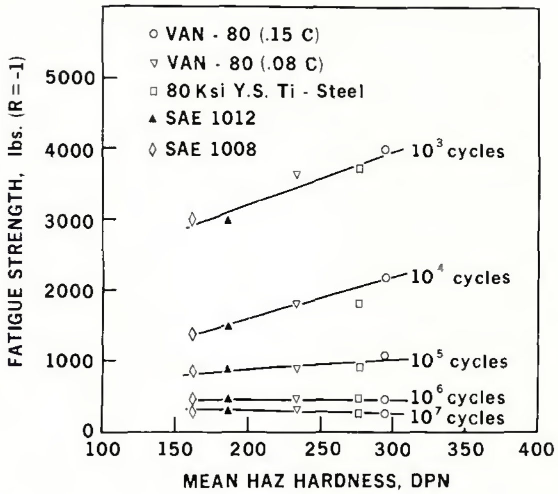

Fig. 21 — Effect of mean HAZ hardness on the fatigue strength of spot welds in 0.073 in. thick material

conditions for spot welding VAN-80 steel are presented in Table 5. These welding conditions are entirely compatible with existing automotive assembly line welding equipment and procedures.

VAN-80 spot welds were found to exhibit twice the tensile shear strength of spot welds in low carbon steel, adequate ductility and similar impact and fatigue properties.

Table 5 — Spot Welding Conditions for VAN-80 Steel

Thickness, in.	Electrode diam., in.	Electrode force, lb	Weld time, cycles	Weld current, A
.050	.25 TC [a]	730	12	7,000-10,500
.060	.25 TC	950	14	9,000-12,000
.070	.31 TC	1200	16	11,000-14,000
.080	.31 TC	1350	17	12,500-15,000
.090	.31 TC	1500	19	14,500-17,000
.100	.375 TC	1800	21	16,000-18,500
.110	.375 TC	1950	23	18,000-20,000
.120	.375 TC	2100	25	20,000-22,000

TC = truncated cone

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