Effect of Fluxes on Steel Joints Brazed with Silver Base Filler Metal

Fluxes were compounded that were superior to American commercial fluxes for minimizing joint defects

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ABSTRACT. This work was part of a study to improve the quality of steel joints brazed with silver base filler metal for Army applications. (Previous work, under this program, on the "Relationships Among Brazing Defects and Brazing Conditions" was published in the Welding Journal, October 1975 issue.)

The study reported in this paper was carried out in two phases. An extensive comparison of American and Russian fluxes was conducted in the first phase using BAg-1 filler metal, 4340 steel and induction brazing. Two Russian flux compositions were found which appeared to have definite superiority over all other fluxes tried with respect to defects in the joint.

In the second phase, six experimental fluxes were compounded from the KBF_4-B_2O_3-KF ternary salt system from which the Russian fluxes that performed well were compounded. The experimental fluxes were tested using the same base metal, filler metal and brazing conditions previously described. One flux produced joints of excellent quality, one flux produced joints of fair to good quality and the other four fluxes produced joints of relatively poor or inconsistent quality.

These experiments indicated that fluxes have considerable influence on joint quality. Further study should be given to more definitely assess the fluxes reported here with respect to anticipated brazing variables (e.g. position, base material, ease of removal, area and orientation of the joint, etc.). In addition, further efforts should be made to formulate new and better fluxes.

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Introduction

The Army, as has been the case with other users of brazed joints, has experienced difficulty at times with brazing defects. Both contractor procured and in-house brazed items contain defects that frequently arouse doubt as to the quality of brazed products.

In some items having requirements for a high percentage of bonded area, for example 85 percent, defects occur in sufficient amounts to cause rejection of items. The causes of the defects are not immediately apparent. As a result, various theories are formed and, upon occasion, stopgap experimental programs are set up to determine the causes of the difficulty.

Although the defect problem has been recognized for some time, little scientific attention has been directed toward its resolution; probably because the majority of such defects and most applications have been of a noncritical nature. However, in ordnance items, quality brazements are almost always considered essential and in any event, improvement of brazed joint quality is desirable. Therefore, methods and techniques that will improve quality are needed.

In the earlier reported work, (Ref. 1) BAg-1 silver brazed steel joints were made, using an induction heated, atmosphere controlled brazing set up. Both conventional and unconventional brazing variables were examined for their role in defect formation.

One of the major findings of the study was that all joints made with flux contained large numbers of defects and it was concluded that their major cause was the irregular flow modes produced by the filler metal-flux displacement mechanism. Unfortunately, this is characteristic of the process at its current state of development. However, since fluxes are so utilitarian to brazing, experimentation was continued to determine if flux improvements could be made which would produce better joint quality.

In the work, which is reported in this paper, a comparison was made of American commercial flux mixtures, a U.S. Navy control flux and Russian flux compositions appearing in the open literature. The American fluxes were purchased on the open market while the Russian fluxes and the Navy control flux were prepared from basic chemicals. Experimental fluxes then were compounded from the ternary salt system represented by two Russian fluxes that demonstrated superior performance. These were tested and the results are given in this paper.

The main thrust of this paper is not to recommend the use of any particular flux. The intent is to show that fluxes do have an effect on the quality of silver brazed joints in steel and that it may be possible to produce fluxes which permit the fabrication of better quality brazed joints in steels.

Materials and Equipment

Induction heating was employed to prepare the brazed specimens. Power was provided by a 20 kW, high frequency induction heating unit of the electronic tube type.

Steel for brazing specimens was SAE grade 4340 in the form of 1 in. (25.4 mm) round bar stock. The nominal composition of the steel is shown in Table 1.

Filler metal for all experiments was 0.031 in. (0.787 mm) AWS grade BAg-1. Its nominal composition is 45% Ag, 15% Cu, 16% Zn and 24% Cd.

Fluxes employed in the phase comparing the American industrial, Russian and U.S. Navy control fluxes were as follows:

Commercial American brazing flux "A", a white creamy paste flux.

Commercial American brazing flux "B", a black paste flux.

Commercial American brazing flux "C", a white creamy paste flux.

Commercial American brazing flux "D", a white creamy paste flux.

Commercial American brazing flux "E", a white creamy paste flux.

Navy Control flux from Specification 51F4a, a white grainy mixture having the following composition: 50%$K_2B_4O_7 \cdot 5H_2O$, 30%KHF_2, 15%KBF_4, 5%H_3BO_3, H_2O to form paste.

Russian flux No. 209 (Ref. 2), a white creamy paste flux having the following composition and mixing instructions: 23%KBF_4, 35%B_2O_3, 42%KF, and 35cc/100g H_2O. To mix, add flux slowly to water. Great heat is released. Fumes are poisonous — use exhaust.

Russian flux No. 284 (Ref. 2), a white creamy paste flux having the following composition and compounding instructions: 40%KBF_4, 25%B_2O_3, 35%KF, and 25cc/100g H_2O. Compounding instructions were assumed to be similar to above due to similarity in composition.

Russian flux PAT (Ref. 3), a white grainy flux having the following composition and compounding instructions: 40%H_3BO_3, 45% KF, 15%KBF_4, and 25cc/100g H_2O. Sift H_3BO_3 and KBF_4 through 2mm screen, weigh and mix. Add KF and water to make thick paste. Can be stored in glass.

Russian flux 3-4 (Ref. 3), a white creamy paste flux having the following composition and compounding instructions: 45.5%H_3BO_3, 37.5%$K_2CO_3 \cdot 1\frac{1}{2}H_2O$, 17%$KBF_4$, and 25cc/100g H_2O. Sift constituents through 2mm screen, weigh out, mix, add water and mix again.

Russian flux 3-6 (Ref. 3), a white creamy paste flux having the following composition and compounding instructions: 61%$Na_2B_4O_7$, 23%H_3BO_3, 16%KF, and 50cc/100g H_2O. Sift $Na_2B_4O_7$ and H_3BO_3 through 2mm screen, weigh out and mix with hot water. Add KF at once and continue mixing.

American flux manufacturers do not make public the composition of their fluxes and the fluxes are difficult to analyze by chemical methods. Therefore, the compositions of the American fluxes are not given in this paper.

Chemicals used in the preparation of the experimental fluxes were potassium fluoborate (KBF_4), anhydrous potassium fluoride (KF) and fused boric acid (B_2O_3).

Fluxes were compounded assuming a ternary composition and increments of 20 percent of any given chemical consituent. This approach permits six compositions to be compounded from the KBF_4-B_2O_3-KF ternary system. One hundred gram samples of each dry flux were prepared by weighing out the various constituents and sifting through a one

Table 1 — Nominal Composition of 4340 Steel, wt %

Element	Percentage
C	0.38 to 0.43
Mn	0.60 to 0.80
P	0.040
S	0.040
Si	0.20 to 0.35
Ni	1.65 to 2.00
Cr	0.70 to 0.90
Mo	0.20 to 0.30
Fe	Rem.

Table 2 — Composition of Experimental Fluxes

Flux	KBF_4 g	B_2O_3, g	KF, g	H_2O, g
1	20	20	60	50
2	20	40	40	40
3	20	60	20	90
4	40	20	40	40
5	40	40	20	70
6	60	20	20	30

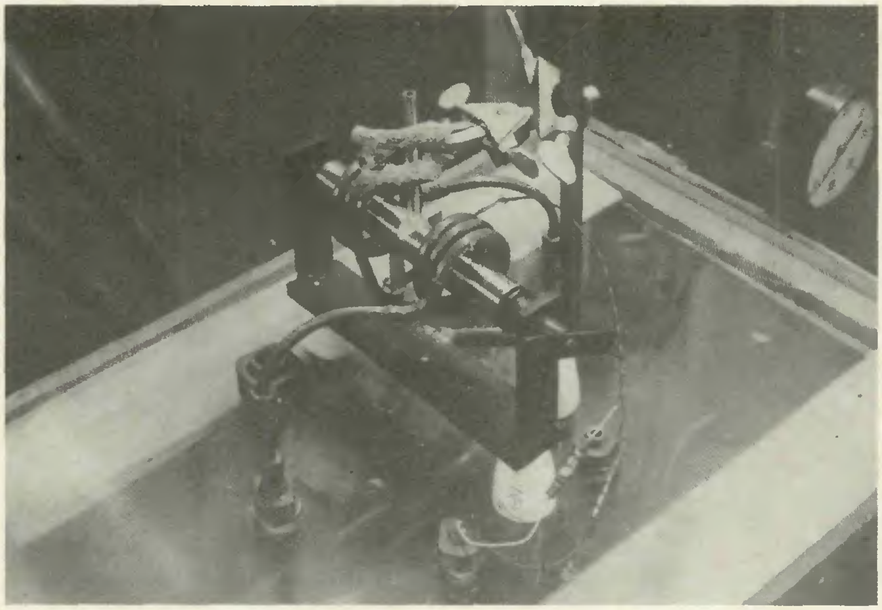

Fig. 1 — Brazing arrangement

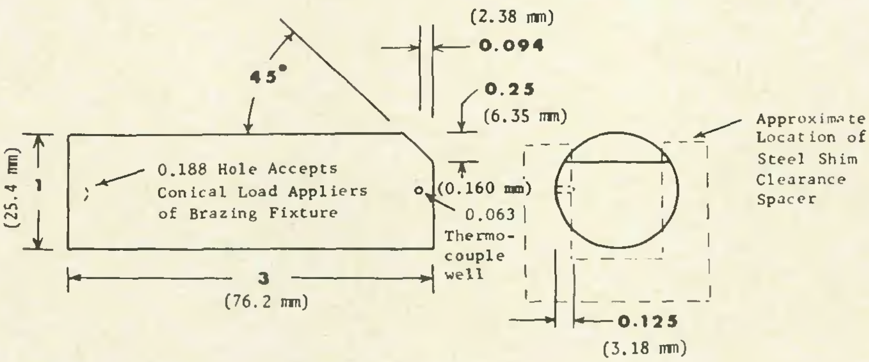

Fig. 2 — Scale drawing of specimen-half used in brazing experiments

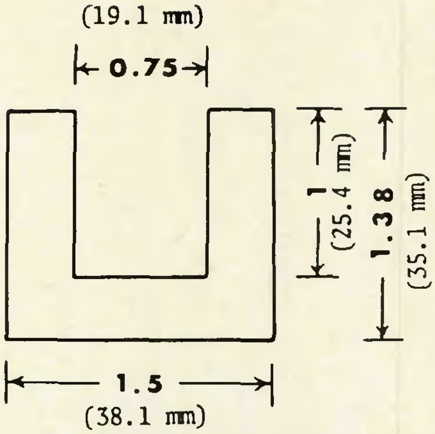

Fig. 3 — Configuration and dimensions of 3 mil steel shims used to maintain joint clearances

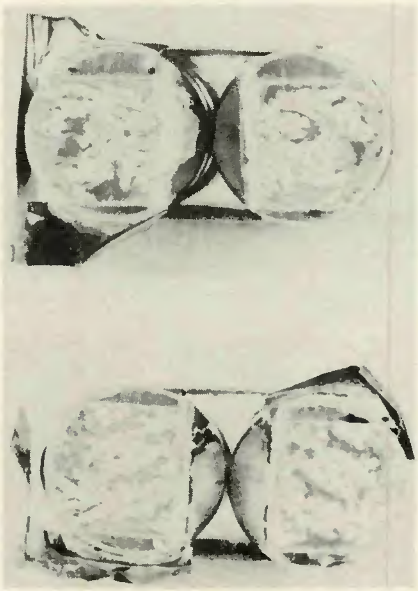

Fig. 4 — Results of induction brazing with American brazing flux "A"

millimeter sieve. Sufficient water was then added to produce what seemed a proper consistency (a medium thick paste).

However, this proved to be a somewhat deceptive practice because fluxes which seemed of the proper consistency when mixed, sometimes thickened upon standing for a few days or even solidified. Since the fluxes were in sealed containers which eliminated the possibility of evaporation, thickening must have been due to chemical reactions. When this happened the fluxes were either recompounded using more water or ground up with a mortar and pestle and additional water added. Excessively thickened fluxes were corrected simply by adding additional water. After these corrections were made the fluxes remained stable. The compositions of the various experimental fluxes are shown in Table 2.

The water contents are believed to be the proper amounts but some of these were altered frequently as previously described and it became difficult to keep track of the exact amounts of water which were present in the final mixtures. Care was also required when adding the water because there was frequently considerable evolution of heat.

The appearance of the experimental fluxes was as follows:

Experimental flux 1, a very smooth creamy flux, white in color. A little thin in consistency.

Experimental flux 2, a very creamy white flux.

Experimental flux 3, a slightly grainy white flux.

Experimental flux 4, a smooth white flux, but very thin.

Experimental flux 5, a grainy flux of thick consistency.

Experimental flux 6, a slightly grainy flux of thick consistency.

Methods and Procedure

Induction brazing was employed as the method for testing the fluxes. Figure 1 shows the induction coil and the method of holding the specimens inside the coil by two point loading of the specimen ends. A thermocouple recorder-controller was also employed to control specimen temperature by activating the induction coil in an on-off mode. A 3 in. (76.2 mm) length of filler metal was preplaced in a quartz guide tube prior to initiation of the brazing cycle. Both the specimens and the filler metal were fluxed and pre-dried immediately prior to brazing so that steam rising from the joint would not foul the inside of the quartz tube. No flux is shown in Fig. 1 because it would obscure details of the brazing arrangement. The quartz guide tube may be observed in Fig. 1.

Figure 2 shows the dimensions and general configuration of the brazing specimens. Two such specimens were butt brazed together to make a completed brazement specimen. The bevels on the specimens were matched during brazing. The bevels facilitated filler metal introduction and also provided a convenient stress raiser so that the specimen could later be easily broken to examine the brazing interface.

Clearances at the brazing interface were maintained by the insertion of 3 mil (0.076 mm) sheet steel shims. Figure 3 shows the dimensions and configuration of the shims. These shims were inserted from the

Fig. 5 — Results of induction brazing with American brazing flux "B"

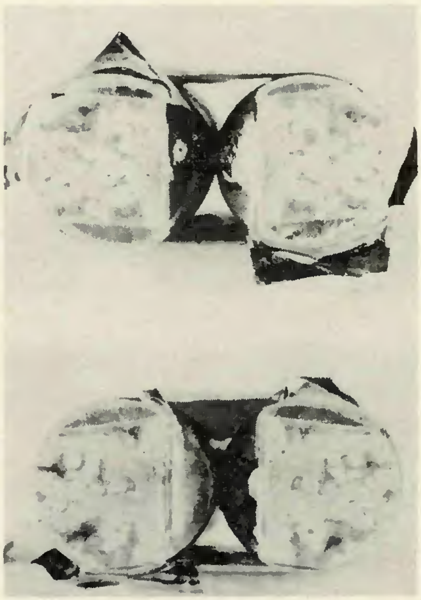

Fig. 6 — Results of induction brazing with American brazing flux "C"

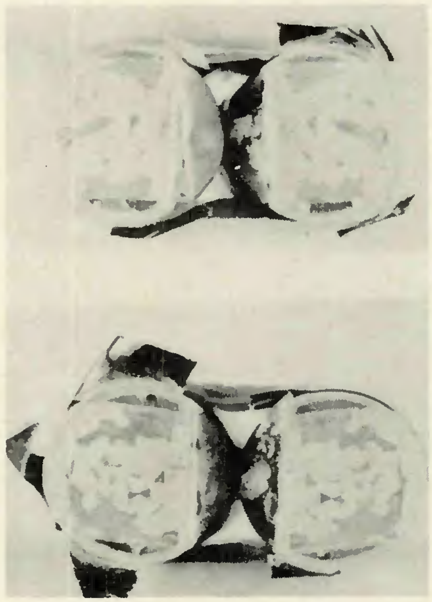

Fig. 7 — Results of induction brazing with American brazing flux "D"

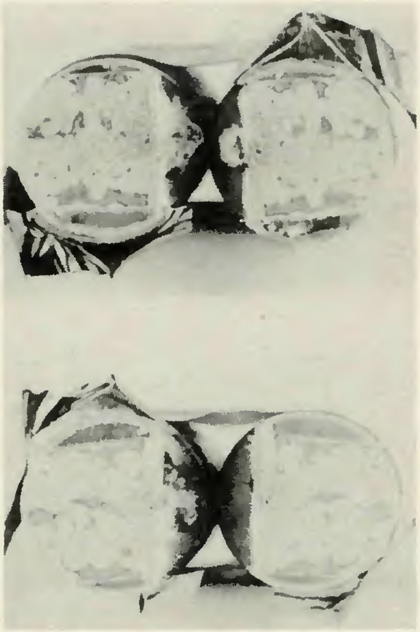

Fig. 8 — Results of induction brazing with American Brazing flux "E"

Fig. 9 — Results of induction brazing with U.S. Navy control flux

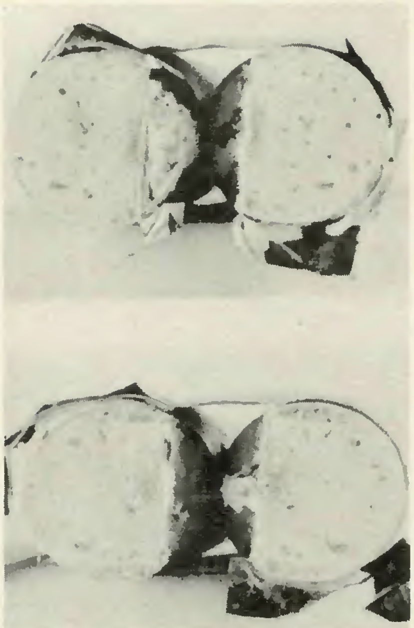

Fig. 10 — Results of induction brazing with Russian flux 209

bottom of the specimens to be brazed, with clearance at the bottom so as to provide a free path for the brazing alloy and flux and yet maintain the desired clearance throughout the entire brazing cycle. The approximate positioning of such shims for brazing is illustrated in Fig. 2.

Specimens were prepared for brazing from the 1 in. (25.4 mm) bar stock by facing off the two ends in a lathe, milling the bevel and then drilling the necessary holes. The surfaces to be brazed were then ground to a three microinch (76.2 μm) finish on a surface grinder. A final step in the preparation of the specimens immediately before brazing consisted of hand grinding the surfaces to be brazed on 1-G grade emery paper, washing in methyl alcohol and wiping dry with a clean, lint-free cloth.

The actual brazing operation was accomplished by fluxing the specimens and placing in the fixture with the shim in place and drying the flux at about 300 F (149 C). A 3 in. (76.2 mm) length of filler metal was cleaned with steel wool, fluxed, and dried in an air-propane flame and then placed in the guide tube. The recorder-controller was then set at 1200 F (649 C) thus activating the induction coil. After the specimen temperature rose and the filler metal melted, the specimen was given one minute at temperature before turning off the induction coil. After cooling, the specimens were removed from the fixture and were broken by three point bent-beam loading so that the brazing interfaces could be examined and photographed. Usually, two specimens were made with each flux except in cases where the flux was obviously completely unsatisfactory.

Results and Discussion

The results that were obtained with American brazing flux "A" are shown in Fig. 4. It can be seen that the joints are about 65 to 75 percent brazed. From external appearances the flux appeared to work well and provide good protection for the steel surfaces but it is obvious from the joints produced that the flux was not completely displaced from the joint and that wetting was not complete in the capillary gap.

Figure 5 shows the results obtained in induction brazing using American brazing flux "B". This is one of the newly developed American black fluxes which have recently appeared on the market. Their chief disadvantage is that they tend to obscure the joint and thus cause difficulties for manual brazing operators. However, in automated brazing operations this is not a problem. The joint quality produced is fair to good on the one specimen, the brazed area being estimated at about 80 to 85 percent. The other specimen is of lesser quality and is only about 60 to 70 percent brazed. In both specimens the entrapment of black flux is readily apparent. Cleaning action of this flux on the exposed surfaces of the specimen seemed excellent.

Figure 6 shows the results of induction brazing with American flux "C". This flux, from external appearances, also seemed to perform well during the brazing operation but as can be seen in the figure the joints were only about 65 to 75 percent brazed.

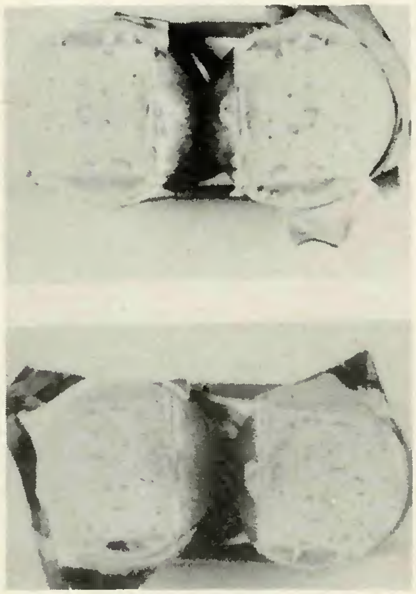

Fig. 11 — Results of induction brazing with Russian flux 284

The results of brazing with American flux "D" are shown in Fig. 7. This is a smooth and creamy flux that to all outward appearances performs well. It keeps the outside of the specimen free of oxidation during brazing. Its performance with respect to joint quality, however, was similar to the joint quality obtained with the other American fluxes, producing an estimated 60 to 75% brazed interface.

The results of brazing with American brazing flux "E" are shown in Figure 8. This flux behaved similarly to the preceding descriptions of American brazing fluxes and was considered typical. It is a white creamy paste that protects the work well and

Fig. 12 — Results of induction brazing with Russian flux PAT

Fig. 13 — Results of induction brazing with Russian flux 3-4

Fig. 14 — Results of induction brazing with Russian flux 3-6

as can be seen in the figure, produced joints that were about 80 percent brazed.

Figure 9 shows the results obtained in induction brazing with the U.S. Navy control flux described in the Materials section of this report. This flux was a little grainy as compounded but seemed to perform well once molten. However, it produced poorer joints than most of the American commercial fluxes. It can be seen in Fig. 9 that the joints were only about 50 percent or less in total brazed area.

Figure 10 shows the results obtained in induction brazing with the Russian flux number 209. This flux is apparently one of the old standard Russian silver brazing fluxes. In use, the flux seemed highly fluid compared to the various American fluxes that were tried and formed thin films on the metal surfaces. However, the results obtained with respect to joint quality were superior to the American fluxes that were tried. Planimeter measurements of 3X blowups of Fig. 10 showed the joints to be more than 96 percent brazed.

Figure 11 shows the results obtained with Russian flux number 284. This flux is very similar to flux 209 both in chemical composition and behavior. In fact, it has exactly the same chemical constituents as flux 209 but in slightly different proportions. It also produced joints that were about equivalent in quality to flux 209. Observation of Figure 11 will show the reader that the joints were about 90 to 95 percent sound.

Fig. 15 — Results of induction brazing with experimental flux 1

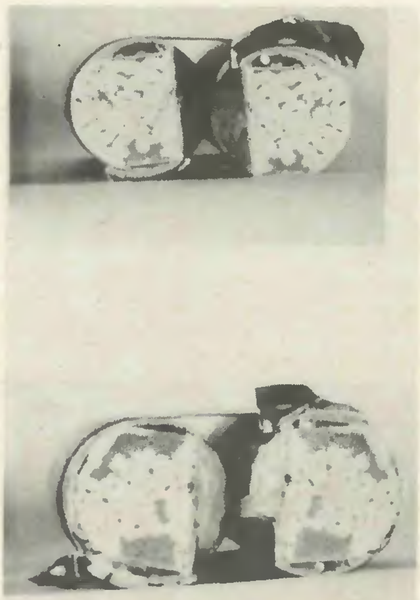

Fig. 16 — Results of induction brazing with experimental flux 2

The results of induction brazing with the Russian flux PAT are shown in Fig. 12. This flux was not good from a number of standpoints. Even though prepared according to instructions it was so grainy that it was difficult to squeeze out of the joint so as to obtain the desired 0.003 in. (0.076 mm) clearance. It also melted peculiarly, producing white islands of dry flux floating on the already molten portions of flux. However, the islands did melt before the brazing temperature was reached. Finally, as can be seen from the figure, poor quality joints were produced having large unbrazed gaps in the center.

Figure 13 shows the results obtained from Russian flux 3-4. This is a creamy flux that is easy to handle and seems to protect the work well. However, with respect to joint quality it produced results about equivalent to some American fluxes tested i.e., approximately a 60 to 70 percent brazed area.

Figure 14 shows the results obtained in brazing with Russian flux 3-6. This is a creamy fine grained mixture of salts and water which from external appearances does not appear to work well. The outside of the specimen oxidizes under the flux and the flux seems to have a higher melting point than most of the other silver brazing fluxes. The melting point as indicated by the recorder-controller was about 1000 to 1100 F (538 to 593 C), whereas most of the fluxes seem to begin melting at about 700 to 800 F (371 to 427 C). However, as may be seen from Fig. 14, the results obtained with respect to joint quality were about as good as were obtained with some American fluxes. The joints were 75 to 80 percent brazed with the usual islands of trapped flux and the finger-like projections of brazing filler metal.

The brazing experiments with the various experimental fluxes produced the following results:

Experimental flux 1 was completely unsatisfactory. The work oxidized badly and the filler metal would not flow or wet the steel properly. This flux was so poor that only one brazed specimen was produced. The fractured interface of the specimen is shown in Fig. 15. This joint was about 65 percent brazed and the filler metal did not flow through the joint.

Experimental flux 2 protected the work well and produced joints which appeared excellent to all outward appearances. When the joints were fractured, one was found to be of good quality and the other showed considerable entrapment and was considered fair at best. The fractured interfaces are shown in Fig. 16. Brazed area was about 85 percent on one specimen and about 65 percent on the other. This flux was the second best of the experimental fluxes.

Experimental flux 3 also seemed to protect the work well and produced joints which appeared to be good from outward appearances. The fractured interfaces, however, showed fairly large areas of entrapment. These may be seen in Fig. 17. The brazed joints were about 65 to 70 percent sound.

Experimental flux 4 was quite fluid and did not seem to protect the work well. However, the outward appearance of the joint was considered relatively good. When the joints were fractured, it was found that the joints were of excellent quality with few and mostly very small defects. The joints were superior to those obtained with the commercial American flux mixtures previously tried. The fractured joint interfaces may be seen in Fig. 18. The joints were about 90 to 95 percent brazed. This was the best experimental flux.

Experimental flux 5 did not appear to work well. The work oxidized under the flux and on one specimen part of the filler metal balled up, did not wet and would not flow into the joint. Figure 19 shows the results of tests of this flux. The joints were poor but did indicate the fallaciousness of observing the opposite side of the joint for filler metal flow-through. It may be seen that the top and bottom of the joints were bonded while a large portion of the center of the joint was not. The brazed area was judged to be about 30 percent in each joint.

Experimental flux 6 did not appear to work well either from outward appearances. The flux appeared to deteriorate and char before brazing temperatures were even reached. The filler metal, when it did melt, would not wet the beveled surfaces of the specimens but balled up and formed contact angles greater than 90 degrees. However, when the specimens were broken one was found to be of very good quality while the other was a complete failure. The two specimens are illustrated in Fig. 20. The anomalous behavior of one specimen as opposed to the other is difficult to explain. The brazed area for one specimen was about 95 percent. The other showed no bonded area.

The two best experimental fluxes (2 and 4) are close to the center of the KBF_4-B_2O_3-KF ternary diagram so this is probably the best area to work in toward refinement of fluxes in this particular salt system. The previously mentioned two best Russian fluxes also are located in this area. Figure 21 illustrates the locations of these fluxes in the ternary diagram.

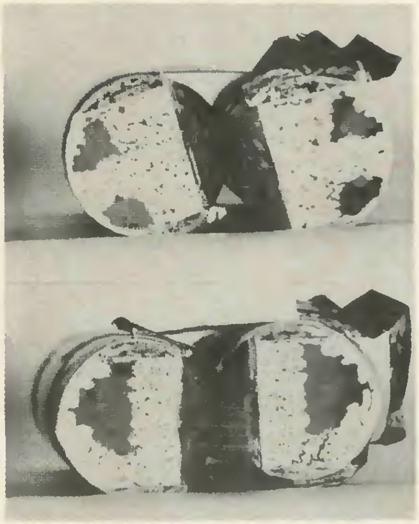

Fig. 17 — Results of induction brazing with experimental flux 3

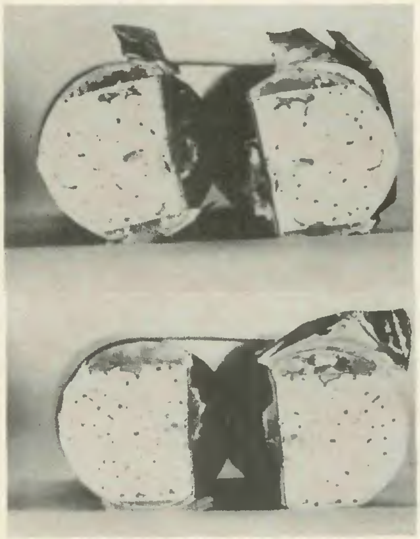

Fig. 18 — Results of induction brazing with experimental flux 4

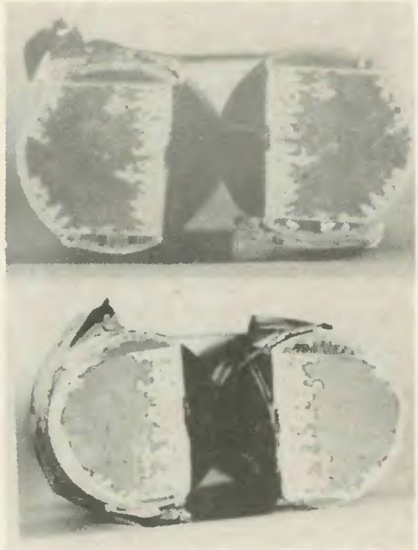

Fig. 19 — Results of induction brazing with experimental flux 5

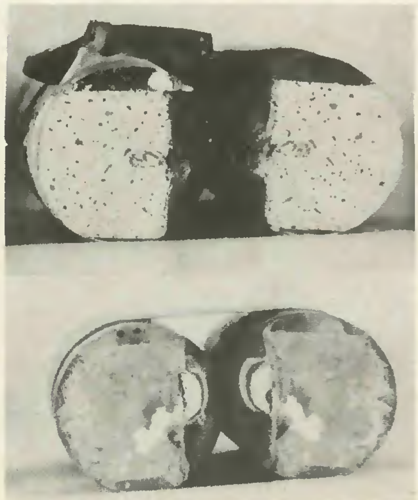

Fig. 20 — Results of induction brazing with experimental flux 6

Conclusions

It has been determined from this work that:

1. Two Russian fluxes produced joints in induction brazing having quality definitely superior to that obtained with the conventional American fluxes studied. These fluxes produced joints 90 to 95 percent sound or better.
2. All American conventional fluxes tried produced relatively similar results with respect to joint quality. These joints were 60 to 85 percent sound.
3. An experimental flux was compounded which produced superior results to the previously tried American commercial fluxes. This flux consisted of 40 grams KBF_4, 20 grams B_2O_3, 40 grams KF and 40 grams H_2O and produced joints about 90 to 95% sound.
4. The best fluxes were located around the center of the ternary KBF_4-B_2O_3-KF diagram.
5. The main observed feature differentiating the superior fluxes from the other fluxes appeared to be their lower viscosity.
6. Joint quality is definitely affected by the characteristics of the flux.

Recommendations

Further testing of the best fluxes as determined in this work should be conducted to further assess their qualifications.

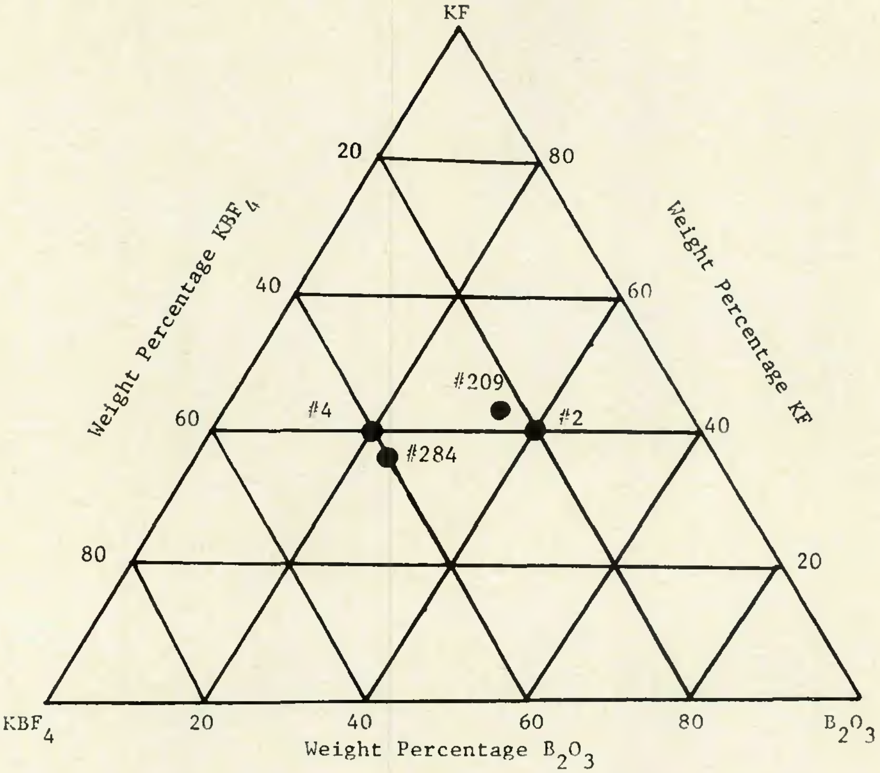

Fig. 21 — Location of best performing fluxes in KBF_4-B_2O_3-KF ternary diagram

Additional study should also be given to the central area of the $KBF_4B_2O_3$-KF system to establish optimum flux compositions and fully characterize the performance of these fluxes.

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