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METALLURGICAL EXAMINATION OF SAMPLES RELATING TO RESEARCH ON THE RESISTANCE WELDING OF GALVANIZED COATINGS

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Samples of zinc coated sheet, spot-welded panels, and welding electrodes connected with research being done at an outside laboratory on the resistance welding of galvanized coatings were examined. It was confirmed that the weldability of different grades of sheet and the mode and rate of deterioration of the welding electrodes was significantly dependent on the nature of the zinc coating. However, apart from the effect of major changes in coating microstructure, the particular factors responsible could not be isolated. Probable factors involved are discussed and areas for further research are suggested.

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INTRODUCTION

In connection with the hot-dip galvanizing research being conducted by the Mines Branch under the auspices of the Canadian Zinc Research and Development Committee, metallurgical examination of various samples and materials associated with AZI - sponsored research on resistance welding of galvanized coatings was requested by the Committee. The samples were received from Mr. N.A. Freytag of the Budd Company, Philadelphia, Pa., and included the items below. Evaluation of the metallurgical structure and weldability of the galvanized coatings, deterioration of the electrodes, appearance of the weld samples and possible correlation between these factors was of principal interest.

TABLE 1

Galvanized Sheet (As-received)

Sample No.	Gauge in.	Coating Wt. each side oz/sq ft	Coating Type
AG	0.035	0.40/0.40	electrolytic
AA	0.034	0.37/0.53	hot dip (minimum alloy)
AK	0.035	0.71/0.65	hot dip (maximum alloy)
AH	0.040	0.25/0.29	galvannealed
AJ	0.038	0.39/0.46	galvannealed
AB6	0.040	0.58/0.46	hot dip
AB8	0.040	0.44/0.54	hot dip
AB9	0.040	0.53/0.60	hot dip

TABLE 2

Electrodes and Weld Panels

Electrode Sample No.	Weld Panel Sample No.	Weld Panel Pretreatment of Sheets	No. of Welds
KAGA			1400
	KAGA	none	100 to 700
KAGC			2200
	KAGC	Electrolytically cleaned + HCl dip	1000 to 1500
KAAB			4400
	KAAB	Electrolytically cleaned + HCl dip	2100 to 2700
KAHB			7000
KAB8A			4100
	KAB8A	none	3100 to 3600

GALVANIZED SHEET SAMPLES

In contrast to the bright spangled finish on Samples AB8 and AB9, the remaining coatings had a spangle-free metallic finish showing varying degrees of brightness and reflectivity. An extreme condition was represented by the dull mat texture of the galvannealed Sample AH. Evidence of a fine grain structure was well-defined on Sample AK and much more so on Sample AA.

The coating surfaces were examined microscopically but only minor differences in surface smoothness and texture were observed. The only effects of any note were the well-defined dendritic structure within the grains on Sample AA and extensive pitting on the galvannealed Samples AH and AJ. It is not known to what extent such effects contributed to the good welding behaviour of these three materials or to the reported high contact resistance of material AA.

Typical microstructures of the galvannealed, fully-alloyed Samples AH and AJ are shown in Figures 1 and 2. Coating thickness and uniformity were much more satisfactory on Sample AJ and the incidence of local breaks or pitting was much less frequent than on Sample AH. The coating on the latter was extensively cracked and chipped and frequently appeared as a thin irregular layer of alloy with local breaks where the base metal was exposed.

At the opposite extreme was the alloy-free electroplated Sample AG. Coating uniformity was good in this case and generally better than on the series of the hot-dip coatings listed in Table 1. Among the latter, Sample AB6 was perhaps the best, while Sample AB8 showed least uniformity on the same and opposite sides of the sheet. This was partly due to irregularity in the steel surface and the same effect was apparent in varying degrees on the other five samples in this group. With respect to iron-zinc alloy formation, all of the hot-dip coatings were much similar to the minimum-alloy type described in a previous investigation (Mines Branch Investigation Report IR 61-114). Including Sample AK, which was stated to have maximum alloy, only a thin discontinuous fringe of iron-zinc alloy crystals was generally present along the steel-coating interface in each case. A typical microstructure is shown in Figure 3.

WELD PANELS

The weld panels submitted and the range of "run-up" welds represented by each are listed in Table 2. On Panel KAGA the welds were clean, sharply-defined, and deep indentation was evident at the lower end of the range represented (100 to 700 welds). The indentation depth gradually lessened and was relatively small beyond approximately 300 welds. All welds had a dull oxidized appearance. The appearance of the welds on Panel KAGC was similar except that indentation was slight but uniform throughout the series represented (1000 to 1500 welds). On the remaining two panels, weld appearance suggested that significant electrode mushrooming and deterioration had occurred. The welds were shallow concave impressions showing no evidence of original electrode geometry and the spots were irregularly contoured due to relief effects associated with indenting and pitting of the electrodes. These effects were more pronounced on KAB8A. On this panel, and also on KAAB, the welds had a bright appearance similar to the surrounding unaffected sheet surface.

Metallographic examination of typical welds from the panels was not attempted after it was found that the welded sheets could be readily separated. The rows of welds representing more advanced stages of testing were of interest and it was in these areas where separation was achieved by forcibly inserting a chisel between the sheets. In the process, only an isolated "button" indicative of a good weld was pulled. In all other welds, minor or negligible joining of base metal was apparent and the sheets were largely held together by fusion of the zinc coating around the welds.

The significance of this evidence of poor quality in the "run-up" welds on the panels is uncertain. As pointed out by Mr. Freytag, the panel welds are not considered representative of actual test welds because of proximity and warping effects. However, the "run-up" weld conditions determine electrode deterioration, which in turn must be reflected in test weld quality. In this connection the frequent incidence of weld overlapping on the panels and resultant indenting of the electrode tips must be mentioned. For these reasons consideration of modifications in "run-up" practice is suggested. This should be aimed at improving the quality of the "run-up" welds, and thereby reducing possible detrimental effects on actual test welds. It is appreciated that this recommendation is based on examination of a few sample panels only. To establish the need for test work in this direction, a more extensive study of a possible relationship between"run-up" and test weld quality appears to be advisable.

ELECTRODE SURFACE APPEARANCE

The five electrode samples exhibited different amounts of wear and pitting deterioration which, in a general manner only, varied according to the total number of welds made with each. Photographs of the contact surfaces are given in Figure 4. Electrodes KAGA and KAGC appeared to be in good condition and there was no apparent evidence to explain their relatively short life, particularly of KAGA (1400 welds). Two electrodes which had given comparable life of 4400 and 4100 welds (KAAB, KAB8A, respectively) differed significantly. The first mentioned showed general pitting of the tip and a minor change in diameter whereas the diameter increase of KAB8A due to wear was gross. Pitting of the latter was confined to a single deep crater. This actually represented coalescence of two separate pits, evidence of which could be seen on the corresponding weld panel. Electrode KAHB had given exceptional service (7000 welds) but, apart from relatively severe wear, additional deterioration was masked by a thick deposit of welding residues on the tip surface.

ELECTRODE MICROSTRUCTURE

Metallographic examination of sections cut through the middle of the electrode tips was made. Some of the typical effects observed are illustrated in Figures 5 to 10 and are described below.

A characteristic feature of all sections examined was the occurrence of a distinct brass layer, identified as the beta copper-zinc phase, adjacent to the copper body of the electrode. Overlying this was a much thicker grey-coloured layer, tentatively identified as the gamma copper-zinc phase. This layer was usually extensively cracked and was locally exposed to the surface because of break-up and tearing away during separation of electrode and work piece at the last weld made. Some of the bright patches evident in Figure 4 presumably represent such exposure of the gamma phase. Elsewhere on the tip surfaces (with exceptions noted later) the gamma layer was covered by what appeared to be a layered mechanical mixture of unidentified welding products including particles of zinc (Figures 6, 9 and 10).

Electrodes KAGA, KAGC

A prominent feature of Electrodes KAGA and KAGC, which had given poor service with electroplated sheet, was the marked mushrooming at the tip edges as shown in Figures 5 and 6. Such deformation suggests excessive surface heating of the electrode which in turn could be expected to increase the rate of alloying of the tip and to affect the nature of the alloying products. Evidence of such effects were observed. As illustrated in Figures 5(a) and 6, beta phase formation for some distance in from the periphery as well as in the vicinity of craters was much thicker than elsewhere. Also, despite the relatively limited welding service, the gamma phase layer was relatively thick and was characterized by severe cracking and break-up as shown in Figure 5(b). No explanation for the apparently aggravated heating operation of these electrodes could be found. However, this must be related to the nature and properties of the electroplated zinc coating, particularly as these affect the welding conditions and the availability of zinc for the electrode alloying process.

Electrodes KAAB, KAB8A

In the metallographic sections of Electrodes KAAB and KAB8A, mushrooming was much less pronounced despite the excessive wear apparent on the latter as shown in Figure 4(d). A typical area on KAAB is illustrated in Figure 7. On these two samples, both of which had given intermediate welding life, the beta phase layer was uniformly thin except in the vicinity of gross surface depressions and pits such as shown in Figures 8(a) and 8(b). Another feature contrasting these samples from the pair described above was the thin, uniform and compact growth of the gamma phase layer. Cracking and break-up in this layer was minimal as shown in Figure 8(c). The absence of adhering secondary welding products apart from a thin outer shell of a third unidentified phase, also to be seen in Figure 8(c), was another dissimilarity. These various features of Electrodes KAAB and KAB8A suggest significant differences in the rate and mechanism of alloying of the tips, presumably, again, because of the nature and properties of the particular type of zinc coating welded. By comparison with Electrodes KAGA and KAGC, lower temperature of operation is indicated and this is supported by the much brighter appearance of the welds on the corresponding weld panels as described earlier. The gross increase in diameter of Electrode KAB8A without any accompanying marked mushrooming also indicates gradual spreading by compression at a reduced temperature. However this is uncertain, in view of the possible influence of the gross pit which developed in this electrode.

Electrode KAHB

On this electrode also, there was little evidence of mushrooming of the type shown in Figures 5(a) and 6(a). Its exceptional service performance with galvannealed sheet was reflected in marked and complex development of thick layers of the copper-zinc diffusion phases and welding residues. Typical microstructures are given in Figures 9 and 10. It is to be noted that in this case only was evidence found of the alpha Cu-Zn phase, as indicated in Figure 9. By comparison with the other four electrodes, the contour of the KAHB tip was very irregular as well as being grossly contaminated. In view of this condition it can only be concluded that welding of galvannealed sheet is much less dependent than normal galvanized or electroplated sheet on the state of the electrode tip surface. The inherently different structure, surface characteristics and other properties of this type of coating, and the reduced amount of zinc available for reaction with the copper alloy electrode, must account for this different response.

DISCUSSION

From the metallographic studies made and the accompanying data provided by Mr. Freytag, it is apparent that three significantly different welding ratings could be applied to the materials AG, AA, AB8 and AH.

The excellent performance of galvannealed sheet (AH) represents one extreme and this was achieved despite apparently severe deterioration of the electrode tip surface. This behaviour is clearly related to the nature of the coating and, being so markedly different, it is unlikely that any useful correlation can be established between the welding response of this and the other materials in question.

Insofar as study of the influence of iron-zinc alloy on the welding behaviour of galvanized coatings is concerned, Mr. Freytag's previous work has revealed the limitations of commercial continuous strip coatings for such experiments. Lack of alloy uniformity and thickness were found to be the principal drawbacks. If further work in this direction is contemplated, consideration should be given to preparation of experimental coatings having controlled and variable amounts of iron-zinc alloy. This could possibly be achieved by electroplating of iron-zinc alloy of desired composition, followed by application of an outer zinc layer by plating or other methods. An alternative method which would, however, offer less latitude in alloy and zinc layer thickness control involves preparation of hot-dip coatings under selected and carefully controlled conditions of immersion time, bath temperature, aluminum concentration of the bath, etc. It will be appreciated that these suggestions are offered as experimental approaches only and little attention has been given to the practical problems and feasibility of producing experimental materials in the quantities which would be required for welding tests.

The opposite extreme in welding performance was represented by electroplated sheet (AG) whereas the hot-dip coating grades (AA and AB8) gave intermediate results. Based on the few electrode samples examined it appears that the performance of these materials was related to variable heating conditions at the electrode-work piece interface and to resultant variations in the mode and rate of alloying and deterioration of the electrode tip. No particular correlation with coating microstructure or surface finish could be established although it is indicated that the welding behaviour of the materials in question was significantly dependent on the nature of the respective coatings. Identification of the dominant factors involved can probably be achieved only by a better understanding of the actual mechanism of deterioration at the electrode tip and investigation in this area is warranted. Suggested work would involve welding runs on different grades of coating with the tests so designed as to permit metallographic examination and evaluation of electrode condition after various periods of service.

A probable factor contributing to weldability of the materials discussed above is the relative purity of the zinc layer which contacts the electrode. A secondary consideration is the distribution of metallic alloying elements present in continuous strip galvanized coatings. Aluminum, for example, is present in higher concentration at the steel-coating interface and it is claimed that lead segregates at different levels in the outer zinc layer depending on the nature of the galvanizing process.

The relative influence of these factors on the thermal and electrical conditions at the spot-welding interface is conjectural. However, the existence of real effects is suggested not only by the poor performance of electroplated sheet but by the variable weldability of hot-dip coatings from different sources as revealed by Mr. Freytag's previous work. Further supporting evidence would necessitate fundamental investigations beyond the scope of the present research and an alternative approach is suggested for consideration. This involves correlating weldability tests with variations in chemical composition through the zinc coating as defined by micro-probe analysis techniques. Such tests would have to be made on relatively thick coatings because of the limitations of the probe technique but this should represent no difficulties in supply.

It is apparent from Mr. Freytag's studies to date that the principal criticism of copper-base electrodes for resistance welding of galvanized coatings is the wide variation in electrode life associated with materials of different gauge, and coating thickness, uniformity and structure. This behaviour cannot justify condemnation of copper-base materials in this application until much more is known about the conditions existing at the spot-welding interface and the factors which affect the welding process. However, the combination of copper and zinc and their high alloying affinity appears to represent a major limitation. For this reason, it is suggested that further consideration be given to investigation of other alloys which would be less prone to wetting and attack by zinc and which would be otherwise satisfactory as electrode materials.

RECOMMENDED RESEARCH

Suggested areas for further investigation on resistance welding of galvanized coatings as outlined in the foregoing text of this report are summarized below. These are not listed in any order of preference or practical feasibility.

1. Study of the influence of "run-up" weld practice on the quality of actual test welds. Any modifications found to be desirable should be incorporated in the items following.

2. Examination of the influence of iron-zinc alloy on weldability of galvanized coatings by tests on specially prepared coatings which provide uniform and controlled thickness of alloy and covering zinc.

3. Study of the mode of deterioration of the electrode tip at selected intervals in the useful life during welding of electroplated sheet and one or more grades of galvanized sheet.

4. Investigation of possible correlation between weldability behaviour of galvanized coatings and variations in chemical composition across the thickness of the coatings.

5. Investigation of new electrode materials.

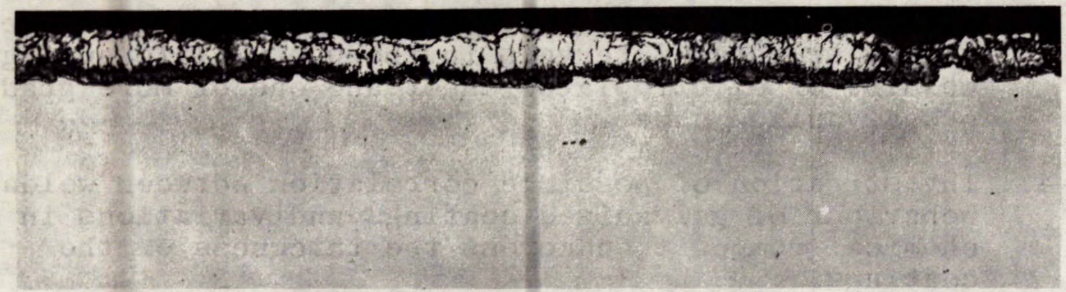


Figure 1. Typical microstructure of galvanized coating AH. Picral etch, X500.

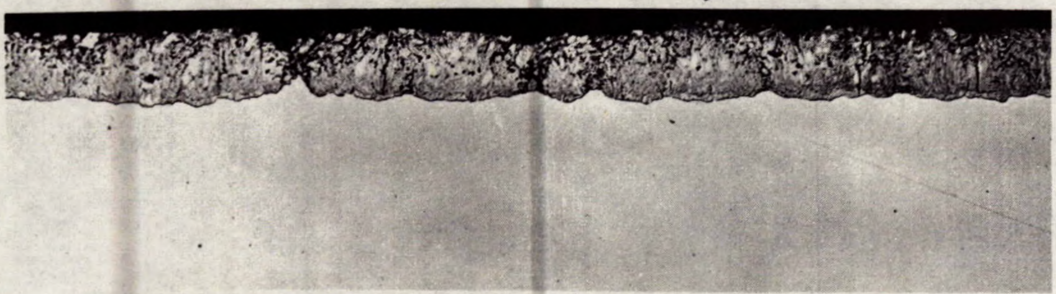


Figure 2. Typical microstructure of galvanized coating AJ. Picral etch, X500.

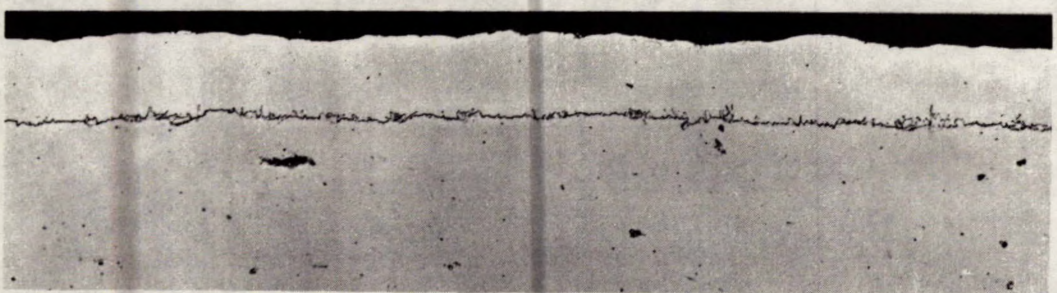


Figure 3. Coating microstructure representative of conventional galvanized coatings in series examined. Nitramyl etch, X500.

(a) KAGA

(b) KAGC

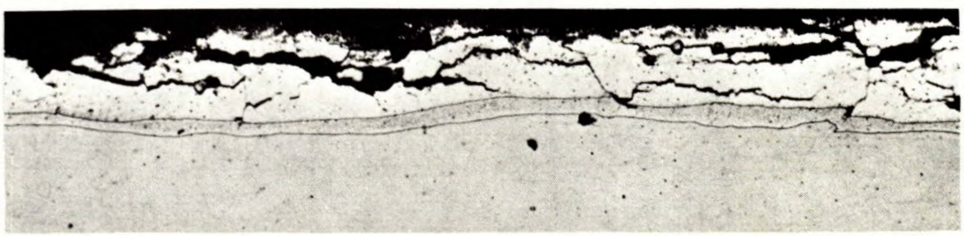
(c) KAAB

(d) KAB8A

(e) KAHB

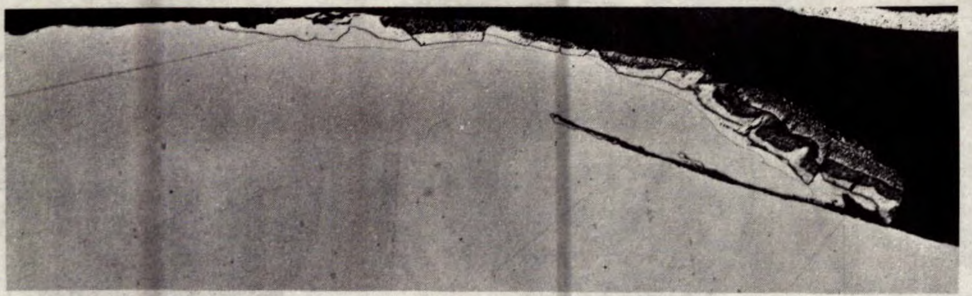
Figure 4. Appearance of electrode tips as identified. X5.

(a) X100

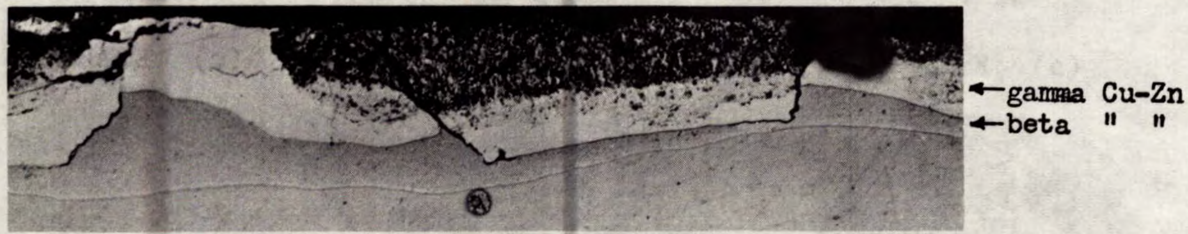


(b) X500

Figure 5. Microstructures of Electrode KAGA showing, (a) mushrooming at edge of contact surface and thick beta phase growth in this area; (b) uniformly thin beta layer and cracking of gamma phase layer in an area remote from the periphery. Ammonia-hydrogen peroxide etch.

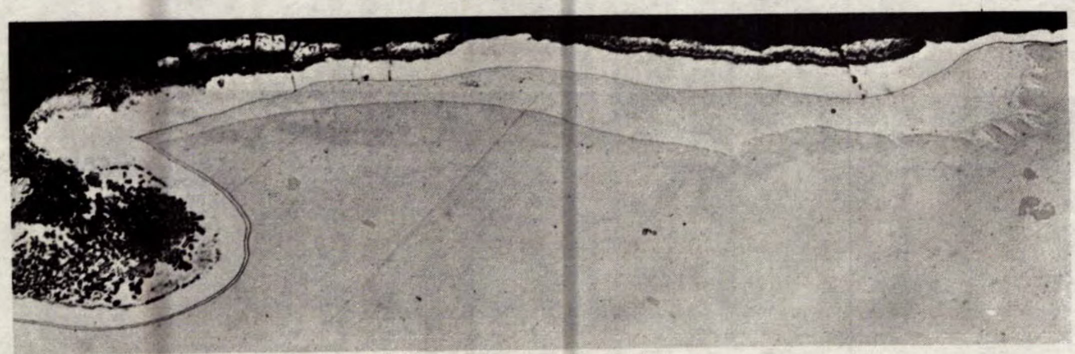


(a) X100



(b) X500

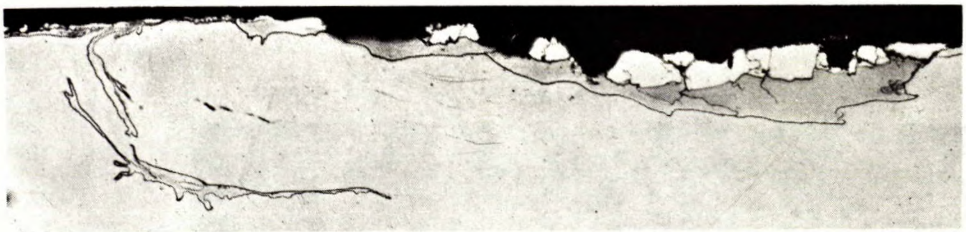
(c) X500



(d) X500

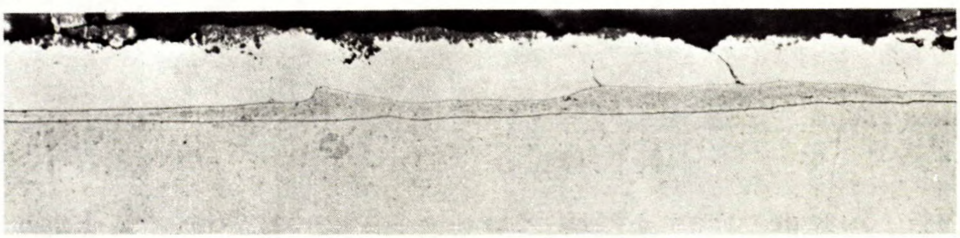
Figure 6. Microstructures of Electrode KAGC showing typical mushrooming at edge of contact surface in (a) and parts of this field enlarged in (b) and (c). An unusual beta phase formation adjacent to a cavity located elsewhere on the electrode surface is shown in (d). Ammonia-hydrogen peroxide etch.

Figure 7. Microstructure of electrode KAAB showing relatively minor mushrooming at edge of contact surface. X100, Ammonia-hydrogen peroxide etch.



(a) X200

(b) X200



(c) X500

Figure 8. Microstructures of Electrode KAB8A illustrating, (a) beta phase penetration and irregular growth in an adjacent shallow depression; (b) cross section through gross pit shown in Figure 4 (d); (c) characteristic growth of beta, gamma and an unidentified outer layer in areas remote from surface irregularities. Ammonia-hydrogen peroxide etch.

(a) X100

(b) X500

(c) X500

Figure 9. Microstructures of Electrode KAHB at low and high magnifications showing complex development of copper-zinc diffusion phases and layered mechanical mixture of other unidentified welding products. The presence of the alpha Cu-Zn phase is to be noted. Ammonia-hydrogen peroxide etch.

(a) X100

(b) X500

Figure 10. Additional microstructures of Electrode KAHB showing typical crater depression in (a) and a part of this field enlarged in (b). Ammonia-hydrogen peroxide etch.