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EXAMINATION OF CARBIDE-TIPPED BURS

by

D. E. PARSONS & K. WINTERTON

PHYSICAL METALLURGY DIVISION

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D. E. Parsons* and K. Winterton**

SUMMARY OF RESULTS

Examination of reject dental burs showed that embrittlement was due to burning which occurred during welding. The hardness of burs in the vicinity of the weld was of the order of Rockwell C 62, indicating the possibility of increasing the steel's toughness by use of a higher tempering temperature.

Control of welding temperature and atmosphere was discussed. Information was also supplied about brazing alloys which might be used in this application.

Hardness gradients were established for as-welded burs tempered at temperatures between 400°F and 1000°F, and for two burs that were given post-weld austenitizing treatments.

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INTRODUCTION

On September 8, 1961, a visit WAS MADE [redacted] by Dr. K. Winterton and D. E. Parsons of the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa.

The purpose of the visit was to observe the procedures used in the manufacture of dental burs and to obtain samples for metallurgical examination. Difficulty had been experienced with excessive rejects by the plant quality control section, which caused concern as the possibility of sale of any defective bur might constitute a public health hazard.

IDENTIFICATION OF SAMPLES

Samples representative of the manufacturing process are listed in Table 1. These samples were subsequently examined to assess the quality of the welds, and of the steel wire, and to determine if a post-welding heat treatment was necessary.

TABLE 1

Samples Representative of Bur Manufacturing Processes

Description of Sample	Code	Condition
As-received, spheroidized wire, heat No. 59	59 AR	Machined blanks
As-received, spheroidized wire, heat No. 60	60 AR	Machined blanks
As-welded, copper-plated burs, oil tempered	W-Cu-OT400	Welded but not finish ground
As-welded burs, without copper-plate	W-OT400	
As-welded burs, reheated to 1500°F and marquenched * (Austenitized 2 min at 1500°F, marquenched 2 min at 500°F)	W-1500-500	Welded but not finish ground
As-welded burs, reheated to 1700°F and marquenched * (Austenitized 10 min at 1700°F, marquenched 4 min at 515°F)	W-1700-515	Welded but not finish ground

* The post-welding austenitizing treatment and marquench were done in molten salt.

Laboratory heat treatments were subsequently carried out, as shown in Table 2, to compare the grain-coarsening tendency of heats 59 and 60 at 2000°F and to determine the tempering temperature that would provide a hardness of Rockwell C 42 to 50 in the "neck" of the bit.

TABLE 2

Samples Examined After Laboratory Heat Treatment

Description of Sample	Code	Condition
Heat 59, wire, carburized at 2000°F	59-C-2000	Carburized for 2000°F grain size
Heat 60, wire, carburized at 2000°F	60-C-2000	Carburized for 2000°F grain size
As-welded:- Tempered 15 min at 400°F*	W-T-400	Welded but not finish ground
As-welded:- Tempered 15 min at 600°F*	W-T-600	Welded but not finish ground
As-welded:- Tempered 15 min at 800°F*	W-T-800	Welded but not finish ground
As-welded:- Tempered 15 min at 1000°F*	W-T-1000	Welded but not finish ground

* Tempered in air.

MATERIAL USED AND MANUFACTURING PROCEDURES

Cold-drawn bars (wires) were supplied by a steel company in 8½ ft lengths. This material was cold-drawn and bright-annealed to provide a spheroidized microstructure and a 80-85 kg/mm^2 tensile strength. The wire diameter was specified as 0.0625 to 0.0628 in. The typical steel composition is shown in Table 3.

TABLE 3

Chemical Composition (Per Cent)

Element	Typical Analysis
Carbon	0.40 - 0.50
Silicon	0.80 - 1.00
Manganese	0.20 - 0.40
Chromium	0.90 - 1.20
Vanadium	0.15 - 0.25
Tungsten	1.70 - 2.10

Information supplied by company personnel indicated that the wire diameter and chemical composition were considered satisfactory for both heats (59 and 60); however, they requested that samples from each heat be compared to detect any difference in grain-coarsening tendency.

The manufacturing procedure has been to weld the tungsten carbide tips onto the steel shank using an oxy-acetylene flame. Two welding practices are used: a manual, and, more recently, an automatic welding procedure. After welding, the normal procedure has been to temper for 15 min in an oil bath.

Brittleness and coarse-grained fractures were observed in the necks of some burs after quality control tests. Experiments with a view to grain refinement were carried out using post-weld heat treatments and austenitizing for periods up to 15 min at 1500°F or 1700°F, followed by marquenching into salt held at 500°F or 515°F.

Subsequently, it was learned that embrittlement of the burs resulted from burning and intergranular oxidation during welding and that, at temperatures close to the burning temperature, grain coarsening occurred. (Information supplied by the manufacturer gave the welding temperature range as 2200 to 2600°F).

The post-weld treatment in which the burs were austenitized 2 min at 1500°F did not effect noticeable solution of the carbide.

Considerably more solution of the carbide was observed in samples which were austenitized at 1700°F for 10 min. In both the 1500°F and 1700°F experiments the marquenching temperature was of the order of 500°F* and, hence, the burs developed full hardness which was not reduced by any subsequent tempering operation.

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* This temperature is below the M_s temperature for this steel.

TTT DIAGRAM FOR STEEL SIMILAR TO THAT USED FOR BUR MANUFACTURE

Figure 1 illustrates a TTT diagram for a steel having similar chemical composition to that used for the burs. The line, ABC, illustrates the cooling curve for the bur sample austenitized at 1700°F and marquenched from a 515°F salt bath, (Sample W-1700-515)

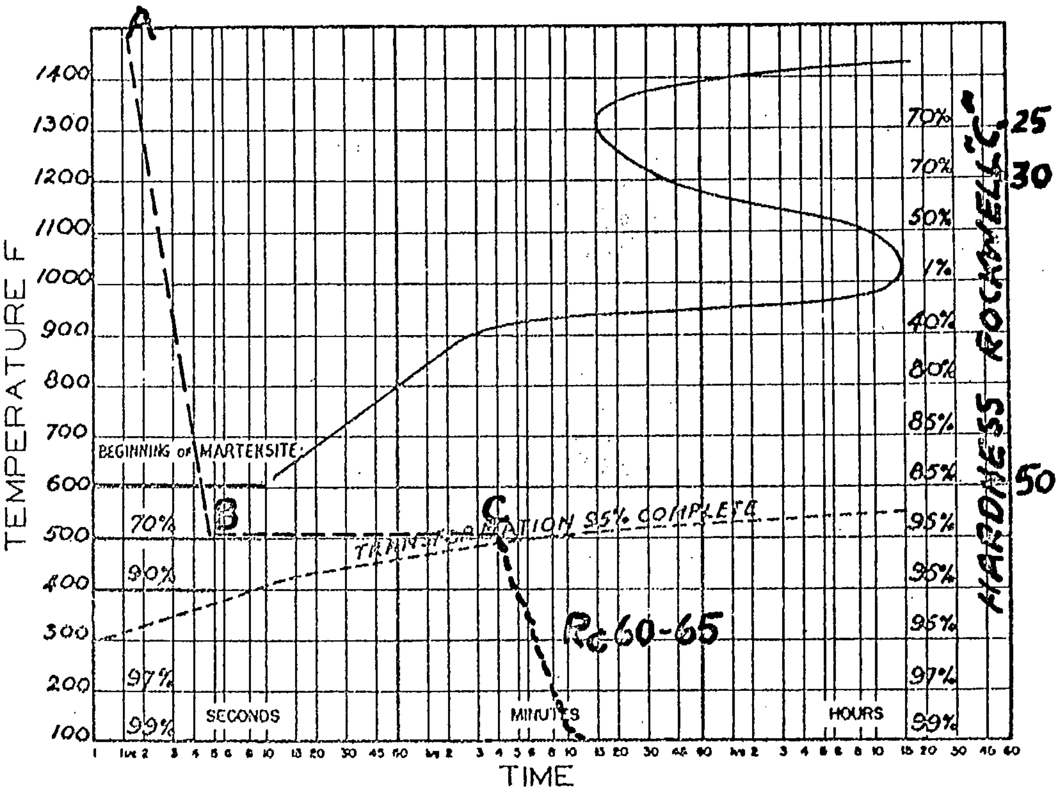

Figure 1. TTT Diagram for a Steel having the Composition C 0.50%, Cr 1.25%, V 0.20% and W 2.75% *(Atha Pneu Steel).

(Austenitizing Temperature 1750°F)

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* Data from Crucible Steel Company.

Hardness surveys taken on burs heated to 1700°F for 10 min and marquenched for 4 min in a 515°F salt bath gave results that varied from Rockwell C 48 in the neck region to Rockwell C 59 to 65 in the thicker shank region and in the pedestal adjacent to the carbide tip.

The low hardness (R_c 48) of the neck region is due to partial decarburization caused by the previous welding operation, or by oxidation occurring in the salt bath.

Figure 2 illustrates another TTT diagram for a steel having a composition similar to that of the burs.

45 WC 20-04

C %	Mn %	Si %	S %	P %	Ni %	Cr %	Mo %	V %	W %	Cu %	As %
0.48	0.27	0.67	0,005	0.010	0.14	1.20	0,015	0.13	2,34	0.21	0.057

Austénisé à : 950°C 1/2 h **Grosseur du grain : 9**

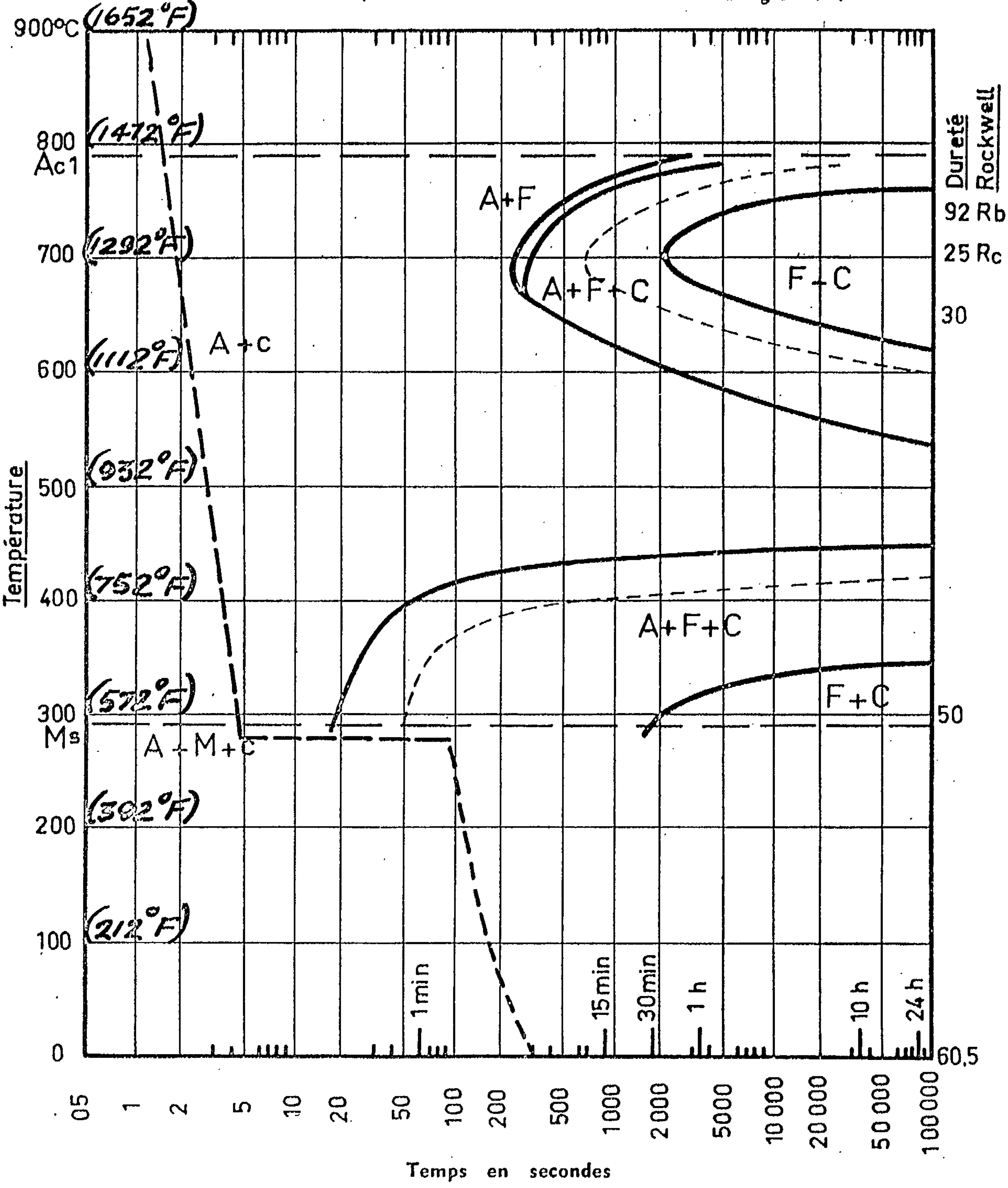


Figure 2. TTT Diagram for Steel 45 WC 20-04

The cooling curve shown in Figure 2 corresponds to the post-weld heat treatment W-1700-515. The present marquench temperatures (500°F or 515°F) appear to be below the M_s temperature for this steel. High hardness (R_c 62 to 65) is developed in the bur by the marquenching heat treatment. If marquenching is used as a post-welding heat treatment, tempering will be required to reduce the hardness to R_c 42 to 48. At present, the microstructure consists of untempered martensite and is brittle. Alternatively, an isothermal austempering treatment could be used with the temperature selected to give a hardness of R_c 45 to 50 (possibly 575 to 600°F). This treatment would avoid the necessity of tempering.

METHOD OF EXAMINATION

Examination of the burs was carried out as follows:

(1). Comparison of wire from heats 59 and 60.

(2) Examination of reject burs.

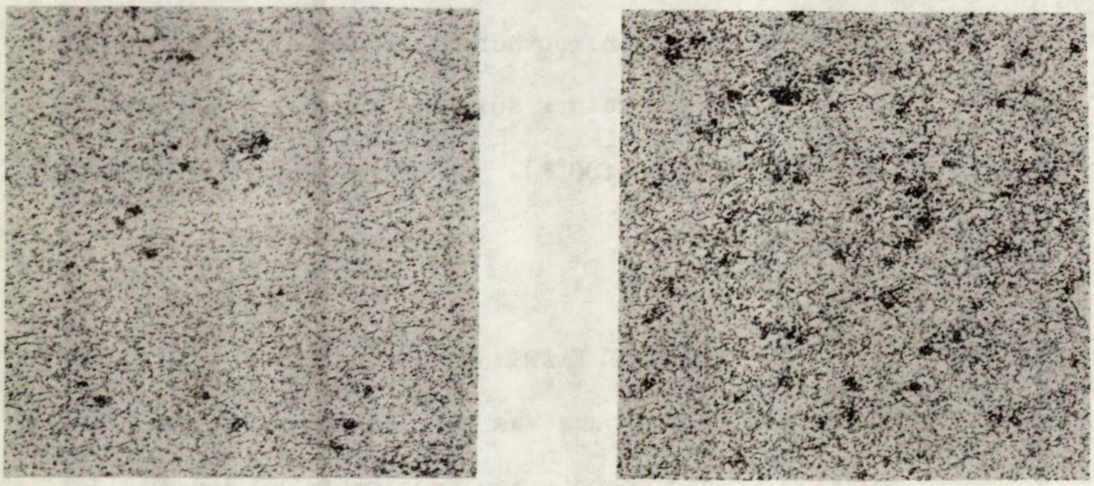
(3) Comparison of the microstructures obtained in burs which received post-weld heat treatments at 1500°F or 1700°F, followed by a 4 min isothermal quench in a 500°F or 515°F salt bath. (Comments regarding salt bath control).

(4) Comparison of the microstructures obtained by tempering of welded burs at 400°F, 600°F, 800°F or 1000°F.

(5) Comparison of the hardness gradient obtained by tempering at 400°F, 600°F, 800°F or 1000°F and of the gradients in the 1500°F and 1700°F samples that received post-weld (grain refining) heat treatment.

(1) Comparison of Wire from Heats 59 and 60

The microstructure of both wires consisted of ferrite and spheroidized carbide with occasional massive particles which probably contained tungsten. The appearance of the as-received wire for the two heats is illustrated in Figures 3(a) and 3(b).



(a)

X500 Etched in 2% nital

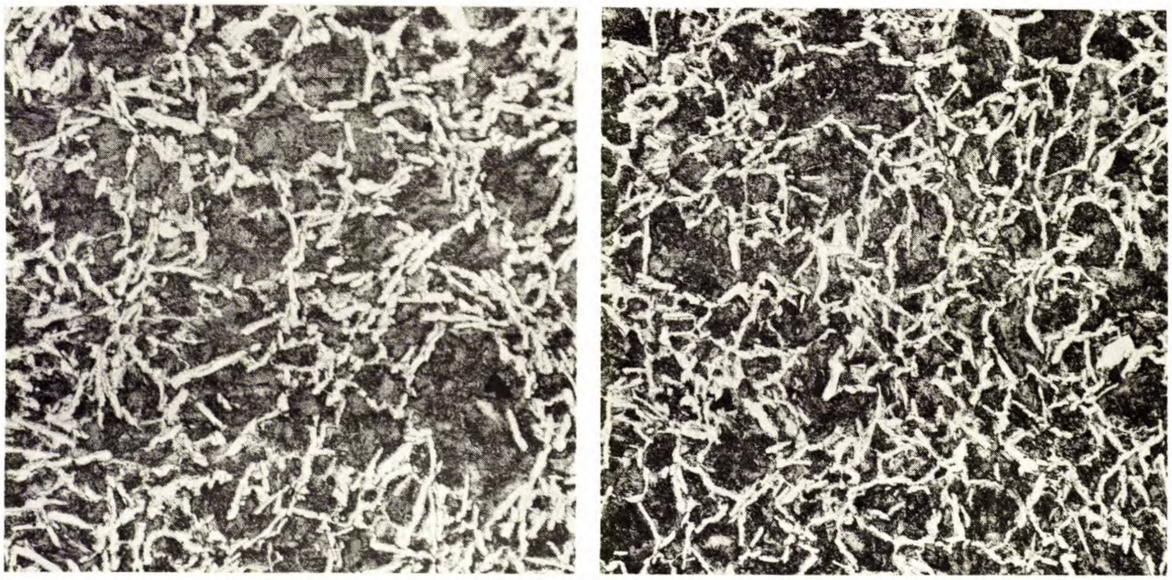
Figure 3. Transverse Section through Wire from Heat 59. (59AR)

(b)

X500 Etched in 2% nital

Transverse Section through Wire from Heat 60. (60AR)

The appearance of cross sections through wires from the two heats after carburizing 2 hr at 2000°F is shown in Figures 4(a) and 4(b).



(a)

X100 Etched in 2% nital

Figure 4. Transverse Section through Wire from Heat 59 after Grain-Coarsening at 2000°F and Carburizing for 2 hr (59-C-2000)

(b)

X100 Etched in 2% nital

Transverse Section through Wire from Heat 60 after Grain-Coarsening at 2000°F and Carburizing for 2 hr (60-C-2000)

No significant difference was observed between heats 59 and 60 with respect to the initial spheroidized microstructure or to grain-coarsening tendency at 2000°F. For the particular sample examined, heat 60 appeared to be slightly dirtier than heat 59, but this difference was not believed to be significant.

(2) Examination of Reject Burs

Examination of reject burs showed that welding temperatures were frequently so high that the steel in the neck and pedestal region was burned and grain boundaries were oxidized. At times, traces of metal which had been liquid at welding temperature were observed at the bottom and side surfaces of the carbide. Most of this metal was removed by the finish-grinding operation and its presence may only be significant where the zone of liquid metal extends beneath the carbide, causing a poor bond and brittle condition at the metal-carbide interface.

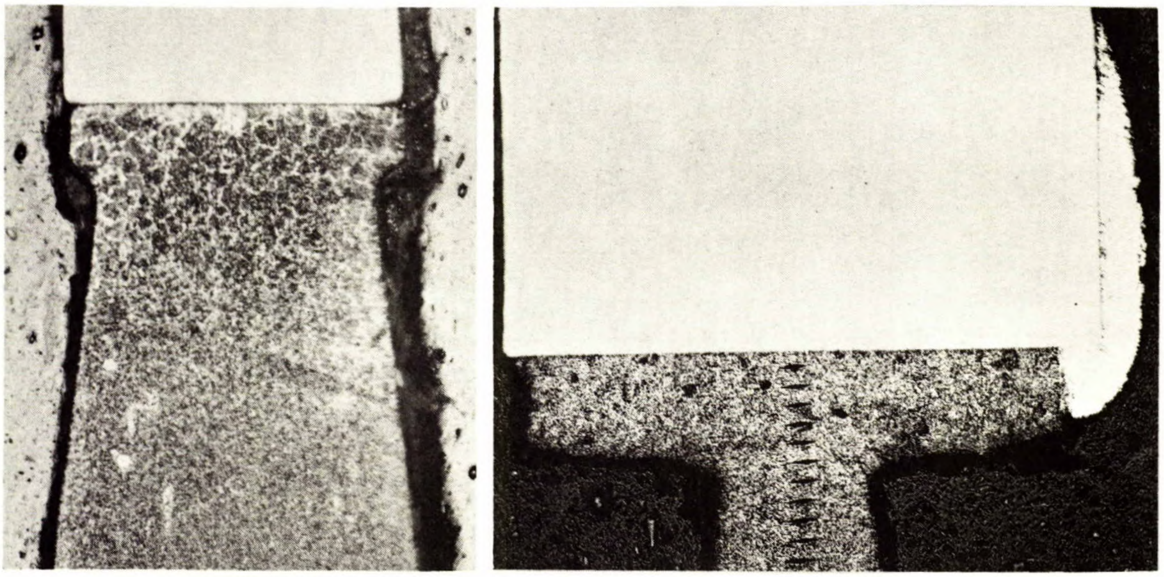
In other instances, burning and formation of intergranular oxides had occurred without evidence of melting. Grain-coarsening was always observed when the steel had been burned and was never observed in samples exhibiting highest strength and toughness.

An intermediate condition also appeared to exist, at temperatures close to, but below the burning temperature, where a coarse-grained structure was formed adjacent to the carbide, but grain boundary oxidation had not occurred.

As the coarsened grains observed in brittle bits were very much larger than those formed after 2 hr at 2000°F by the laboratory heat treatment, it is likely that grain-coarsening only occurs at temperatures close to the burning (liquidus) temperature and, hence, the appearance of coarse-grained fractures should warn of the necessity for reduction in welding temperature.

Another serious condition was observed when burning and formation of grain boundary oxides occurred, whereby oxidized intergranular cracks were left which extended inwards from the surface. The presence of a crack in a finished bur would have a serious notch effect and could cause brittle failure under relatively small loads. These cracks would be difficult to detect prior to service.

The appearance of an as-welded bur exhibiting grain coarsening (incipient or actual burning) and of another bur where liquid metal has been present at the interface between the carbide and the steel are illustrated in Figure 5(a) and 5(b), respectively.



(a)

(b)

X50 Etched in 2% nital

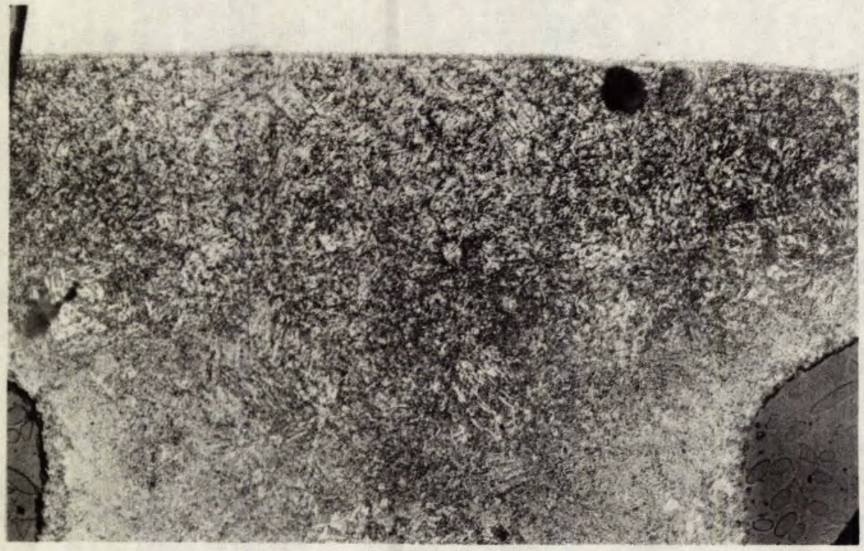
X50 Etched in 2% nital

Figure 5. (a) As-Welded Bur Showing Grain-Coarsening (Incipient Burning) at the Carbide Metal Interface. (W-T-400)

(b) As-Welded Bur Showing the Presence of Metal which was Liquified at the Interface and Side Surface During Welding. (W-T-400)

The appearance of an unburned bur in the as-welded condition is shown in Figure 6(a) with a portion of the weld zone illustrated at higher magnification in Figure 6(b).

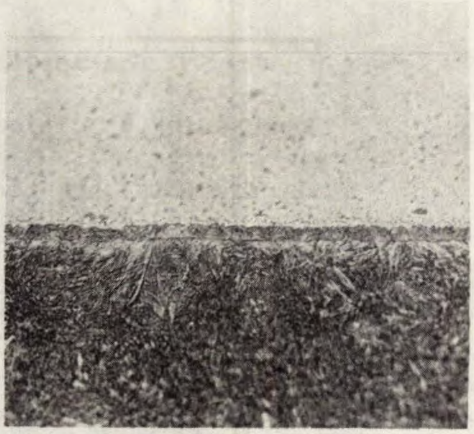
The appearance of an intergranular crack that was oxidized and open to the surface is illustrated in Figure 7.



(a)

X200 Etched in 2% nital

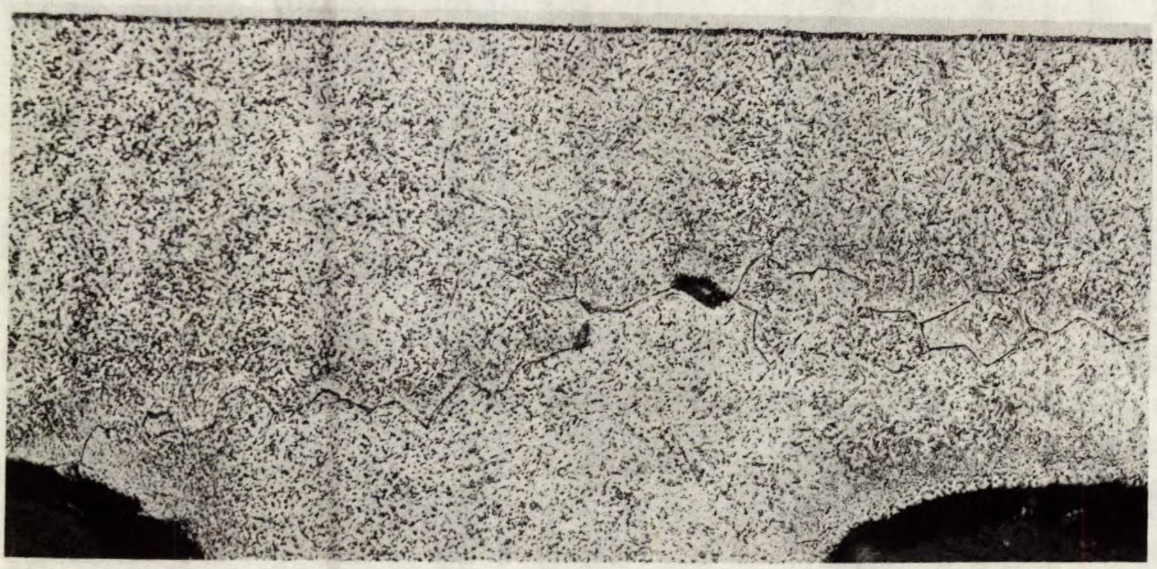
Figure 6. Unburned, Welded Bur. Unburned weld zone consisting of martensite and transformation product. (W-T-400)



(b)

X500 Etched in 2% nital

Weld Interface. The serrated interface of the weld zone and the presence of at least two compound layers between the carbide and the steel is visible. (W-T-400)



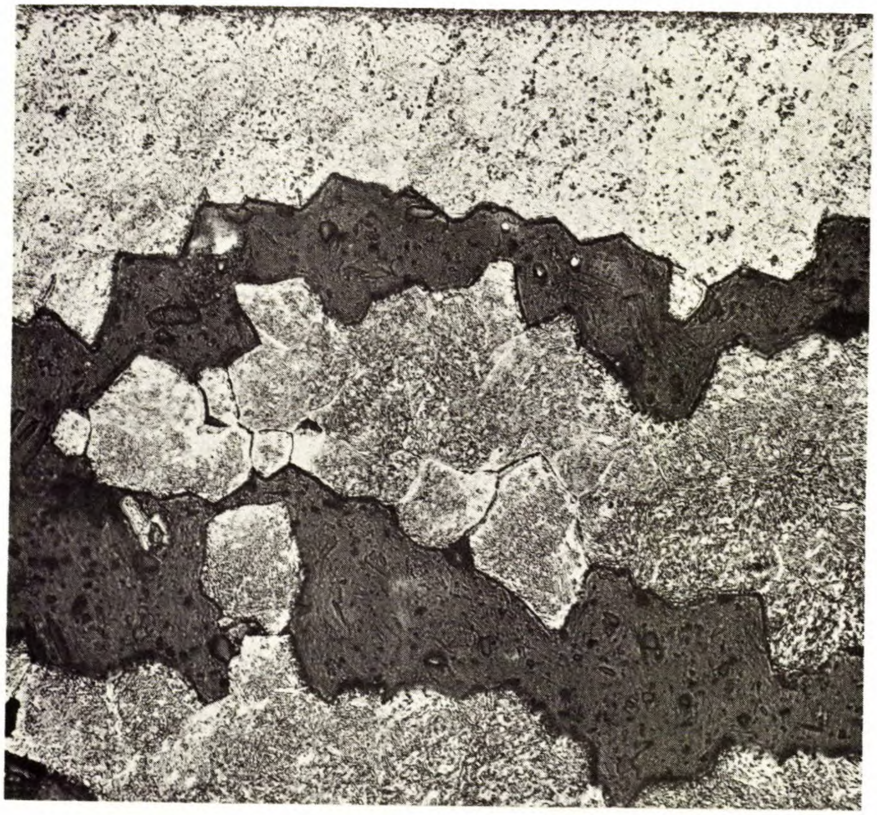
X200 Etched in 2% nital

Figure 7. Intergranular Surface Crack in Burned Bur.

This type of crack was probably caused by excessive welding temperature under oxidizing conditions and presents a dangerous notch that is difficult to detect during final inspection (W-T-400).

Copper-Plated Burs

The intergranular separation present at the fractures of copper-plated burs after welding is illustrated in Figure 8. A low melting point, copper-rich, constituent is believed to be present in the grain boundaries. This constituent would have the effect of lowering the burning temperature of the steel and would constitute an extra hazard during the welding operation.



X200 Etched in 2% nital

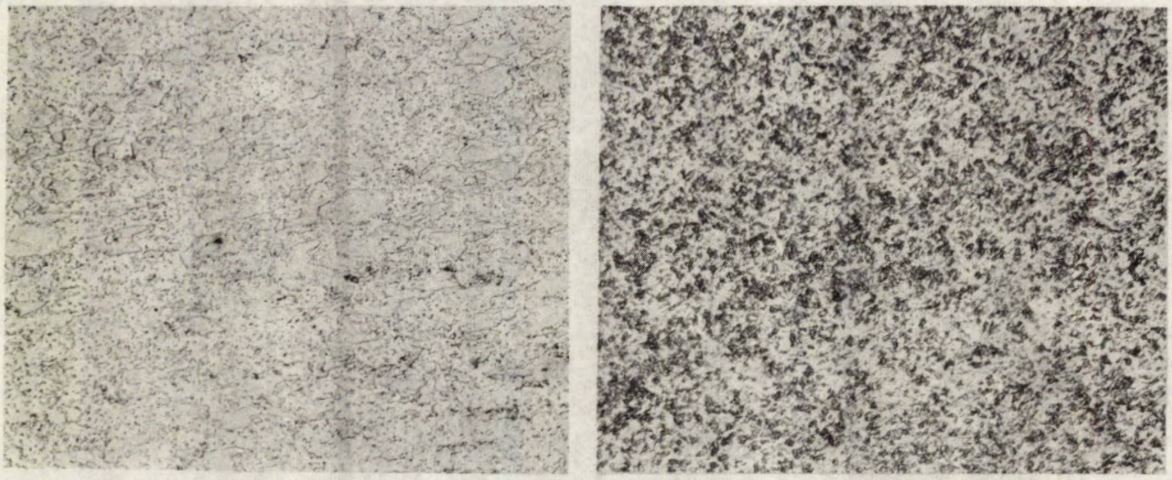
Figure 8. Intergranular Crack Present in Copper-Plated Bur after Welding. (W-Cu-OT 400).

The fracture resembles a "creep" failure with intergranular separation along oxidized grain boundaries.

(3) Comparison of Microstructures Obtained After Post-Welding Heat Treatments

The microstructure obtained, when welding was followed by a 1500°F reheat for 2 min followed by quenching into salt at 500°F and holding 2 min at temperature, is illustrated in Figure 9(a) for the shank region of a bur.

Similarly, the microstructure obtained in the shank region after reheating for 10 min at 1700°F and quenching into salt at 515°F, is illustrated in Figure 9(b)



(a)
X500 Etched in 2% nital

(b)
X500 Etched in 2% nital

Figure 9. (a) Transverse Section through the Shank of Sample W-1500-500. The microstructure consists of martensite, ferrite and undissolved carbide.

(b) Transverse Section through Shank of Sample W-1700-515. The microstructure consists of martensite bainite and considerably less undissolved carbide than was observed in Figure 9(a)

A salt bath was used for the 1500° and 1700°F austenitizing treatments, and some decarburization may have been caused by this bath. The salt should be rectified and maintained in a non-oxidizing condition by insertion of a graphite electrode in accordance with recommendations made by the Salt Supplier.

(4) Comparison of Microstructures Obtained in As-Welded Burs which were Tempered for 15 min at 400°F, 600°F, 800°F or 1000°F

It was observed that welding produced a very hard zone of martensite and bainite in the fusion zone adjacent to the carbide. This probably resulted from increased hardenability due to grain-coarsening, from the chilling action of the carbide, and from complete solution of carbide at the welding temperature.

Tempering was successful in reducing this hardness so that the as-welded hardness, R_c 62 to 65, was reduced to R_c 48 in the pedestal region after tempering 15 min at 1000°F.

Except for the hard region mentioned (adjacent to the carbide) a gradient of transformation products occurred through the neck of the bur and onto the tapered part of the shank. At one point the temperature gradient coincided with the A_{c1} temperature (1330°F approx) and microstructure beyond this point was unchanged from that of the as-received wire.

These tests indicated that use of a tempering temperature up to 1200°F is probably possible without hazard of soft shafts, and that, by this means, the brittle region adjacent to the weld can be stress-relieved and toughened if burning does not occur during welding. (Deflection tests would be required to prove this).

The degree of grain coarsening and burning (observed in the twelve as-welded burs which were used for the tempering tests) varied so that some burs were definitely burned and others exhibited grain coarsening. About 50% of the as-welded burs probably would have been satisfactory if an adequate tempering treatment had been used. However, the 15 min oil tempering treatment at 400°F was not effective in softening the hardened metal in the vicinity of the weld.

Possibly, satisfactory burs can be manufactured (if the welding operation is controlled) by use of a higher tempering temperature subsequent to welding.

(5) Comparison of Hardness Gradients

Hardness Gradients Produced by Tempering Tests

The hardness gradients obtained by tempering as-welded burs for 15 min at 400°F, 600°F, 800°F or 1000°F are shown in Figure 10. The hardness of the as-welded burs, prior to tempering, varied between R_c 54 and R_c 65 in regions adjacent to the weld and in the narrow, neck section of the burs. The hardness present after welding and the results of the tempering tests suggest that a tempering temperature in excess of 1000°F would be necessary (after welding) in the absence of other post-weld heat treatments.

The four tempering curves show that, during welding, the A_{c1} temperature (approximately 1330°F) is reached about 0.10 in. from the weld interface. At this point the hardness drops rapidly and between 0.10 and 0.20 in. the minimum hardness is obtained coinciding with the thick end of the tapered portion. The hardness values between the 0.20 in. and 0.60 in. positions represent the hardness of the as-received wire.

Hardness Gradients Produced by Austenitizing Tests

Theoretically, the heat treatment after welding, whereby burs were heated in salt for 10 min at 1700°F and were then transferred to a salt bath at 515°F for 4 min, should have produced a uniform martensitic structure having a hardness of R_c 60 to 65. In the heat studied, either the salt bath was oxidizing, or welding caused decarburization in the critical neck section of the bur, so that this region was only hardened to R_c 48. The presence of this decarburized metal, at R_c 48, would prevent adequate tempering of the R_c 60 to 65 zones because any reduction of hardness in the neck to less than R_c 48 might cause failure by deflection. In the absence of decarburization the 1700°F, 515°F marquenching treatment could be used, provided this was followed by a tempering treatment to reduce the hardness to R_c 42 to 50.

Alternatively, the burs could be transferred from the 1700°F furnace to a furnace at 600°F or higher and could be held for about 1 hr to give a hardness of about Rockwell C 50. (This method would be an austempering treatment and subsequent tempering would be unnecessary).

Choice of the 1700°F austenitizing temperature agrees with the austenitizing temperatures suggested for the steels shown in the TTT diagrams. At this temperature most of the carbide was taken into solution with the 10 min soak. (Longer soak periods at 1700°F were stated to cause reduction in the cutting efficiency of the carbide). This treatment did effectively refine the grains in the weld region PROVIDING THE STEEL WAS NOT BURNED DURING WELDING. When burs were burned during welding, salvage was impossible.

For the 1500°F austenitizing test shown, the temperature and soak time were too low to effect any appreciable solution of carbide; hence, the hardness gradient resembled that for the as-welded burs except in the vicinity of the weld where prior heating during welding had placed the spheroidized carbide in solution.

The 1500°F austenitizing temperature is below the theoretical A_{c3} temperature and, for this reason, refinement of the coarse-grained weld structure was not obtained.

The hardness results are summarized in Figure 10.

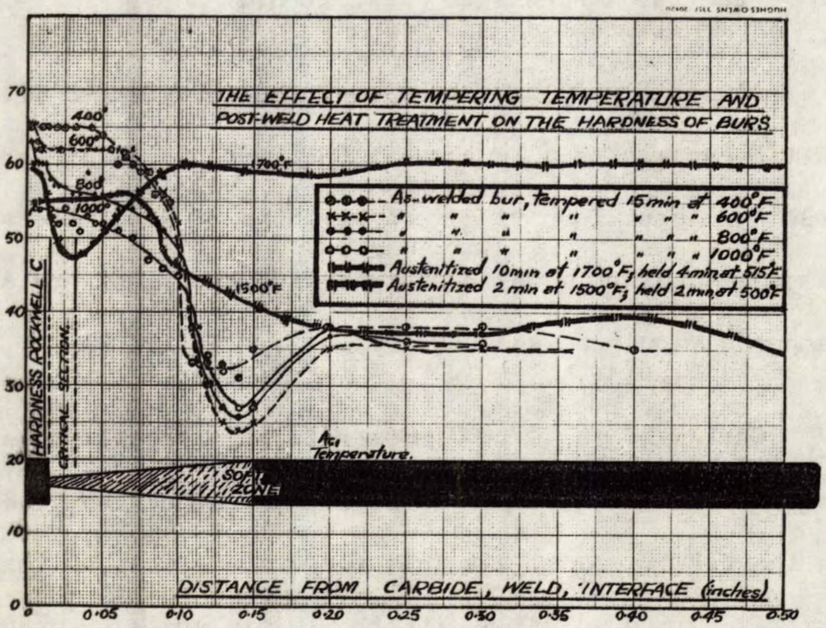


Figure 10. Hardness Gradient of Burs Tempered at 400°F, 600°F, 800°F or 1000°F and of Burs that Received 1500°F or 1700°F Post-Weld Austenitizing and Marquenching Heat Treatments.

SUMMARY AND DISCUSSION

The burs fail as a result of burning, ie, welding at a temperature too close to the liquidus temperature. The presence of an oxidizing atmosphere may have contributed to the intergranular oxidation. (In the worst instances, considerable metal had been liquid during welding).

If burs are not burned during welding, tempering at a temperature of 1000°F or higher should reduce the hardness in the weld region to Rockwell C 42 to 50 and will probably provide a satisfactorily tough bur. (This method would not effect any refinement of the weld zone grain size -- however, it is believed that good welding or brazing practice would cause minimum grain-coarsening and refinement would be unnecessary).

The presence of copper plating on welded burs is believed to increase the likelihood of defects by lowering the burning temperature of the grain boundaries.

Some burs which have been burned contain oxidized intergranular cracks that are open to the surface and can act as severe stress raisers, probably causing notch-brittle failure during quality control tests, Provision for detection of these cracks may be necessary prior to sale.

None of the burs have been sufficiently tempered to provide adequate toughness in the neck and pedestal region.

Decarburization of the neck region during welding or during any subsequent heat treatment should be avoided because this will affect the hardness gradient developed on quenching and will restrict the choice of tempering temperature.

If a post-weld austenitizing treatment is considered necessary for increased strength, an austempering treatment would probably be more suitable than the present treatment. If marquenching is used, subsequent tempering will be necessary to reduce the hardness to R_C 42 to 50. If either of these treatments is used, the austenitizing temperature should be above the A_{c3} temperature (1700° approx.) to achieve grain refinement. The effect of the 1700°F treatment on the carbide should also be determined.

The appearance of a coarse-grained fracture is believed indicative of excessive welding temperature and probably means that the steel cannot be salvaged by heat treatment. Use of brazing alloy or control of welding temperature and atmosphere are required to avoid burning and decarburization.

DISCUSSION OF WELDING AND BRAZING PROCEDURES

Joining Methods for Dental Burs

Welding

The present joining method using oxy-acetylene heating is attractive, since strong joints are often obtained. However, it is difficult to control, and the metallurgical investigation makes it quite clear that most of the present difficulties stem from insufficient control of the welding temperature, leading to occasional overheating and burning of the steel.

The automatic system used [redacted] [redacted], evidently has some advantages over the manual systems. However, the flame size and length and the character of the flame (ie, oxidizing, neutral or carburizing) are decided by manual adjustment and subjective judgment. The time period of the welding operation, which appeared to be in the order of 6 sec, can be regulated more easily with the automatic controlled cycle.

The fully automatic control of the time and temperature of the welding operation would be complex and quite expensive.

As a compromise, it might be found easier to control the present operation if the flame temperature was reduced, so that the welding time became less critical. It is well known that the oxy-acetylene flame gives very high temperatures (5500°F). Experiments would be necessary to see whether the lower flame temperatures of oxy-hydrogen (4800°F), oxy-propane (4700°F) or air-hydrogen (3700°F) might give a more desirable result.

It has been mentioned that the welding temperature is selected from the range 2200 to 2600°F. Overheating and burning is liable to occur with temperatures in the range 2500 to 2750°F, and it is apparent from the metallurgical evidence that these phenomena do occur. If the present system must be adhered to, an attempt should be made to control welding temperatures within the range 1900° to 2200°F, with the latter as a top limit, to avoid the possibility of serious defects appearing.

Brazing

The development of brazing alloys has proceeded rapidly in the last decade, and it is possible that an alloy could be selected which would give sufficiently high strength, so that satisfactory joints could be more consistently attained, without the risks of burning and overheating attendant upon welding.

For example, Colmonoy "Nicrobraz" developed for jet engine work has been used to join alloy steels, tool steels, carbides, etc. The recommended brazing temperature is 2100°F. This is a very hard alloy and would have to be applied as a mixed powder with brazing flux. Another possibility is the alloy of 15%-manganese-in-silver alloy. This flows at 1780°F and, presumably, brazing could be accomplished at around 1850°F.

Both of these brazing alloys are characterized by high strength. An advantage of the second alloy is that it is available in sheet form of various thicknesses. Discs of the alloy could be cut and pre-placed using the present automatic system, in order to try out the idea.

In either case, since the brazing temperature would be in excess of the ideal austenitizing temperature, post heat-treatment would be necessary to achieve optimum properties, though tempering alone might be sufficient for satisfactory properties.

The idea of selecting a brazing alloy for use at 1700°F does not look attractive, as this would restrict the strength obtainable.

If brazing was found to be advantageous, after trying out the idea under present production conditions, consideration could then be given to further modification of production methods in a way more appropriate for the brazing technique.

CONCLUSIONS

1. Brittleness in burs was caused by burning and intergranular oxidation occurring during welding.

2. Even when burs were not burned, they appeared to be excessively hard in the pedestal and neck region adjacent to the weld, (R_c 60 to 65) indicating that a tempering temperature higher than 400°F should be used.

3. Decarburization occurred in the neck region of burs during welding and during the austenitizing treatment, causing low as-quenched hardness at the neck section. (This might cause trouble from the viewpoint of deflection tests and would restrict the choice of tempering temperature).

4. Copper-plated burs are more susceptible to burning than unplated burs.

5. Comparison of the 2000°F grain sizes and as-received microstructures for heats 59 and 60 revealed no significant difference between the heats.

6. If burning is avoided during welding, and if the tempering temperature is adequate, use of a post-weld austenitizing treatment may not be necessary. (Mechanical test results will be required to clarify this question).

7. If a post-weld heat treatment is necessary, use of the 1700°F austenitizing temperature appears preferable to 1500°F. However, use of the present marquenching treatment necessitates an adequate tempering treatment to reduce the as-quenched hardness from R_c 60-65 to R_c 42-50.

8. If a post-weld heat treatment is necessary, use of an austempering treatment should be considered, because this treatment can develop the correct hardness without a final tempering treatment.

RECOMMENDATIONS

1. Consideration should be given to the remarks in the discussion of welding and brazing procedures. Control of welding temperature, to avoid burning, should be achieved or experiments should be carried out with high strength brazing alloy.

2. Mechanical tests should be made on burs which have not been burned and which have been tempered (at 1000 to 1200°F) to R_c 42 to 50 before a decision is made about the necessity of a post-weld austenitizing heat-treatment.

3. If a post-weld heat-treatment is considered necessary, use of the 1700°F austenitizing temperature, followed by an isothermal "austempering" treatment, should be considered providing the carbide is not damaged.

4. If the post-weld 1700°F marquenching heat-treatment is continued, a tempering treatment subsequent to hardening should be used to increase the toughness of the metal in the pedestal region of the bur.

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