

Evidence of grain growth was also observed where soldering was carried out electrically in a furnace, or without the use of flux. In these cases, however, the final grain size within the solder was similar to that in the parent alloys.

Table IV shows the size of grains measured using the intercept method. Grain growth was at a level considered to be highly significant.

A study of table IV points out the following;

- (i) Grain growth occurs following soldering,
- (ii) Where grains are larger before soldering, as seen in Thermotrol castings, the grain size after soldering is greater than in castings with smaller grain size before soldering.
- (iii) In similar type castings, more grain growth occurs when soldering is carried out electrically than with a gas-air blow pipe, and the grain size in the solder and original alloys tend to be the same.
- (iv) Where soldering is carried out without flux, approximately the same amount of grain growth occurs in the parent alloys, as when flux is used, but the grain size in the solder is larger than where flux is used.

Gap Size.

Sufficient gap distance between the castings to be joined was necessary for a successful soldering operation.

TABLE IV.

The Effect of Soldering on the Grain Size of Dental Casting Gold Alloys and Gold Solder.

	Mean Grain Diameter (Microns)		
	Before Soldering	After Soldering	
	Gold Alloy	Gold Alloy	Solder
Thermotrol Casting (Gas-air Soldering with Flux).	280	800	150
Gas-air Centrifugal Casting (Gas-air Soldering with Flux).	140	400	150
Gas-air Centrifugal Casting (Electrically Soldered with Flux).	140	500	500
Gas-air Centrifugal Casting (Gas-air Soldering without Flux).	140	380	300

This has been studied in detail by Ryge (1958).

Figure 13 shows the effect of soldering where castings were in contact. Incomplete union occurs where the gap is too small. Grain structures of the solder are very different from the parent alloys, the grains being smaller. Capillary action did not seem to work well under these conditions.

Soldering seems to be most successful and accomplished with greatest ease where a gap size between 0.004 inches and 0.006 inches is provided. Such a joint is shown in figure 14 where soldering was carried out using vaseline based flux, gas-air blow pipe with 18K gold solder.

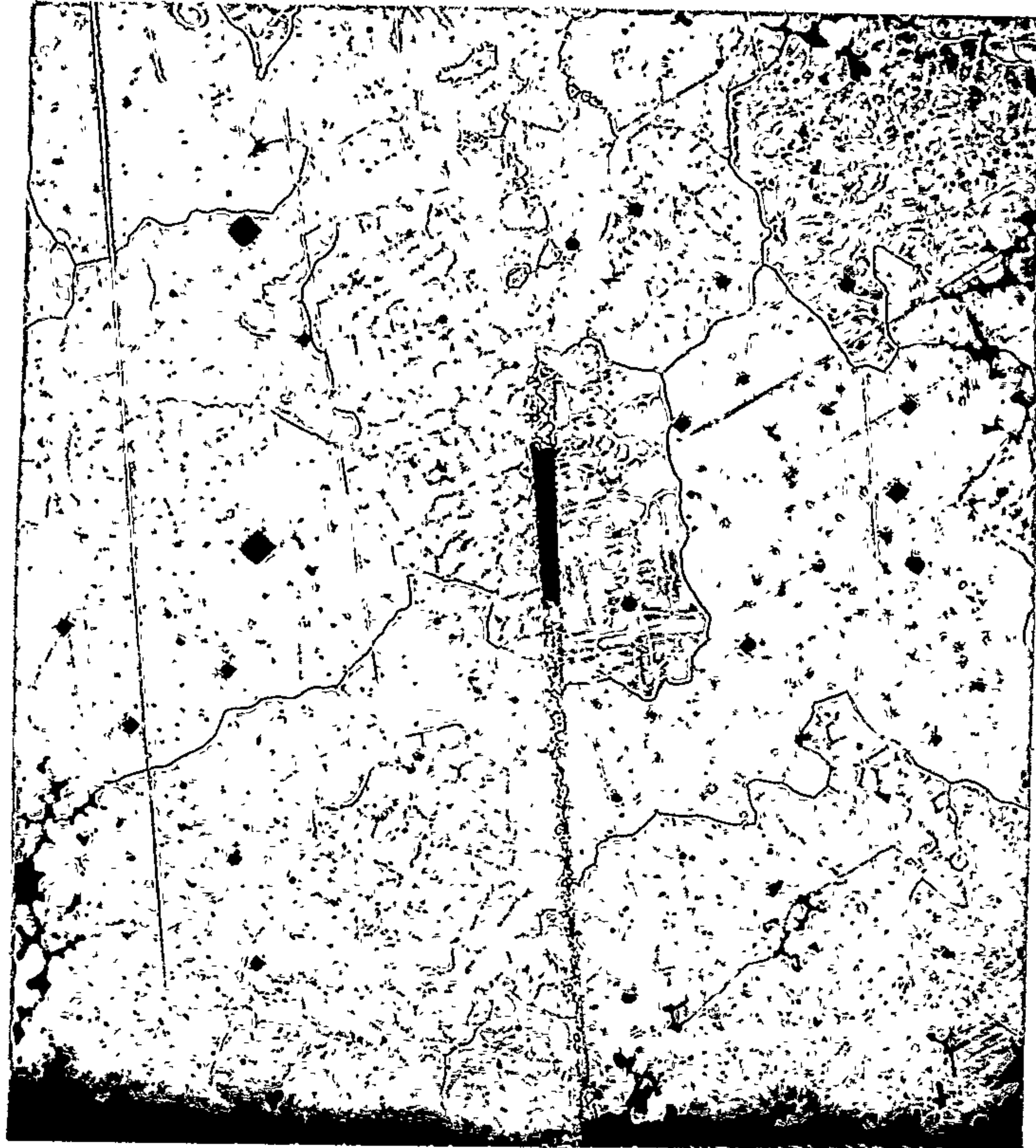
Apparently successful soldered joints may be formed with larger gap sizes, and gaps as wide as 1 mm. may be bridged with solder.

Surface Preparation.

It was found in this investigation that the surfaces of castings to be joined need not be dentally polished. Provided that surfaces were clean, soldering could be satisfactorily carried out and it was difficult to distinguish polished and unpolished surfaces after the soldering operation.

Figure 15 shows the result of soldering where different surface preparations, of the castings, have been used.

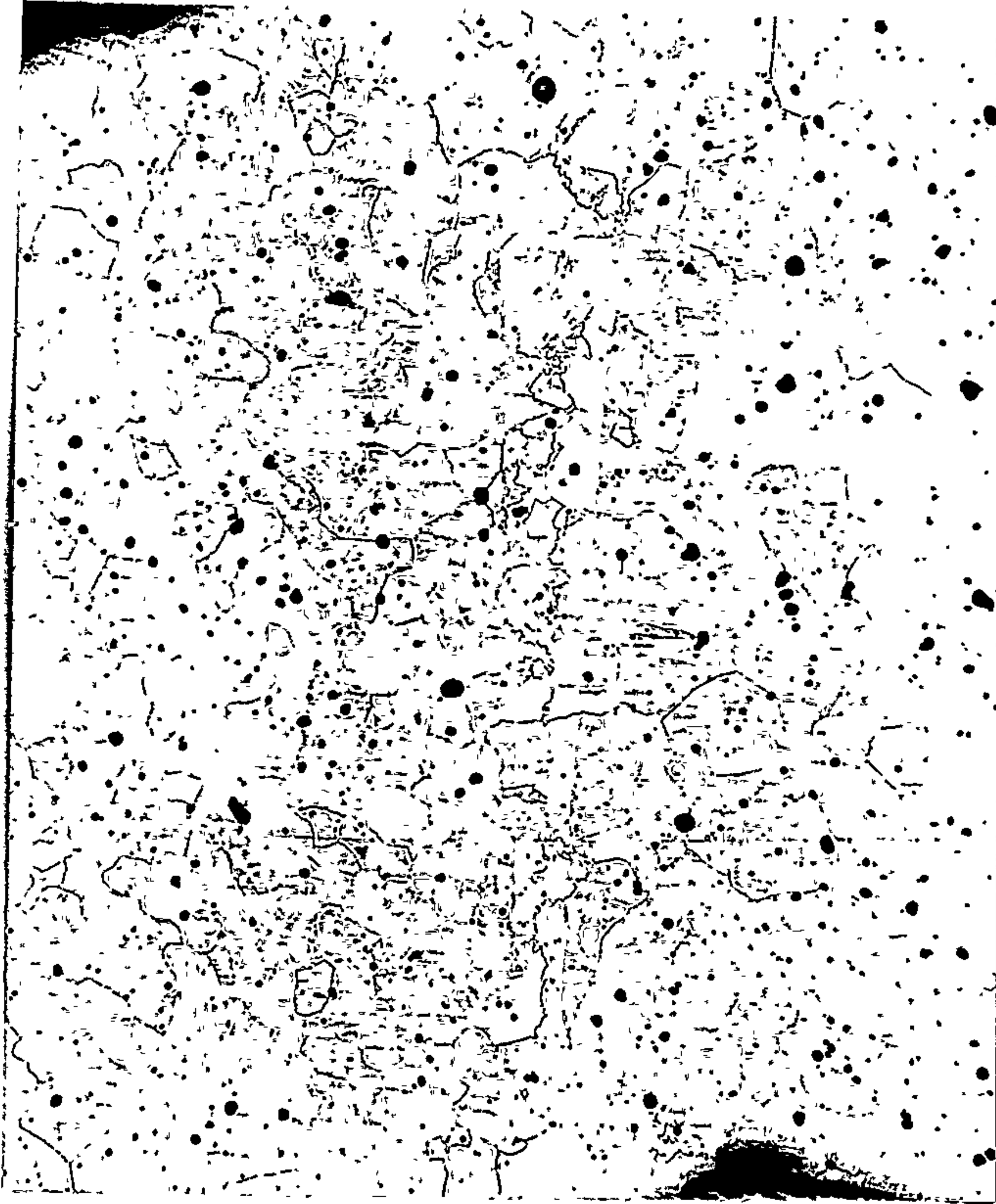
82a.



Castings in contact before soldering.
X50.

Figure 13.

82b.



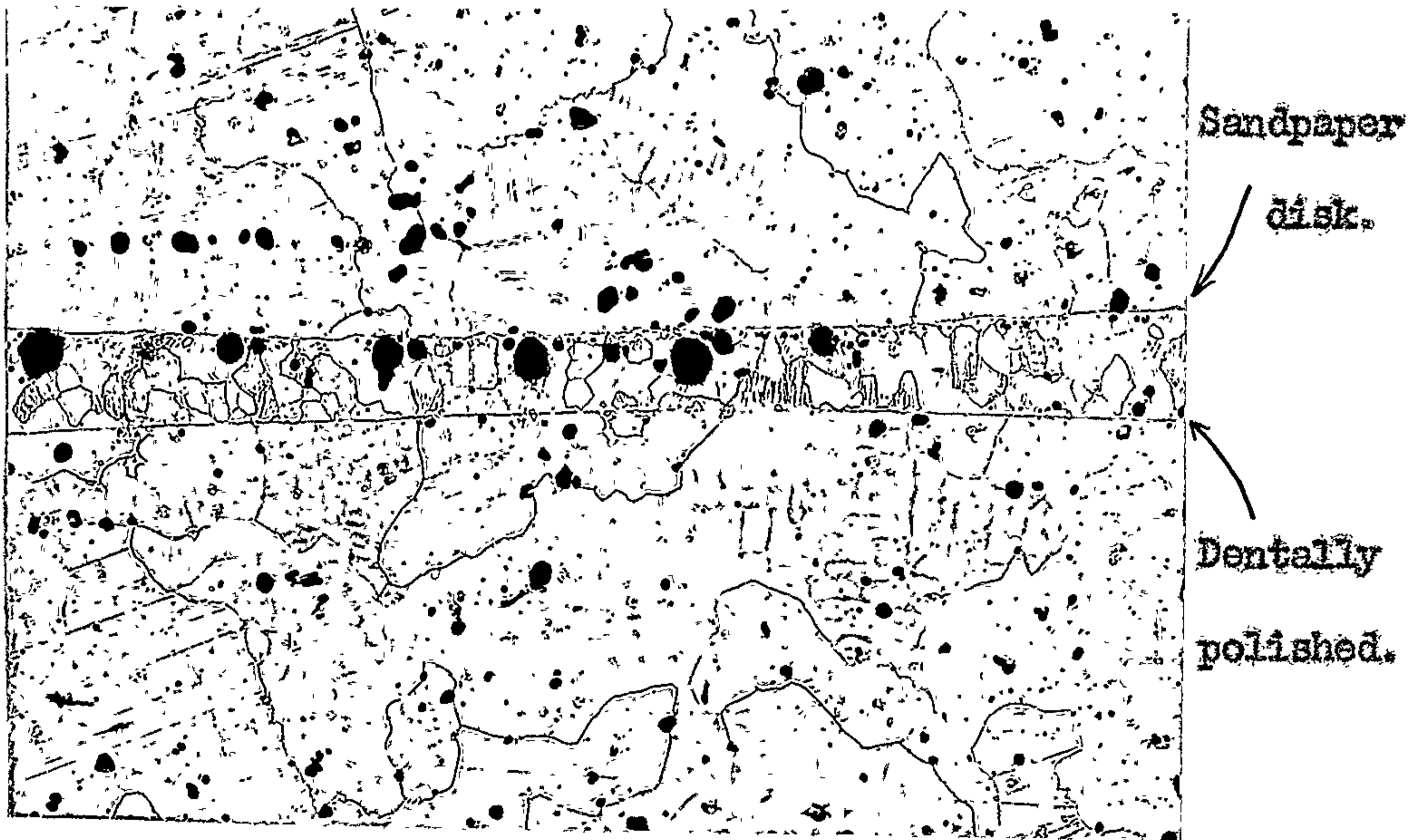
Gas-air Soldering.

.006 in. > gap size > .004 in.

X50.

Figure 14.

82c.



X50.

Figure 15.

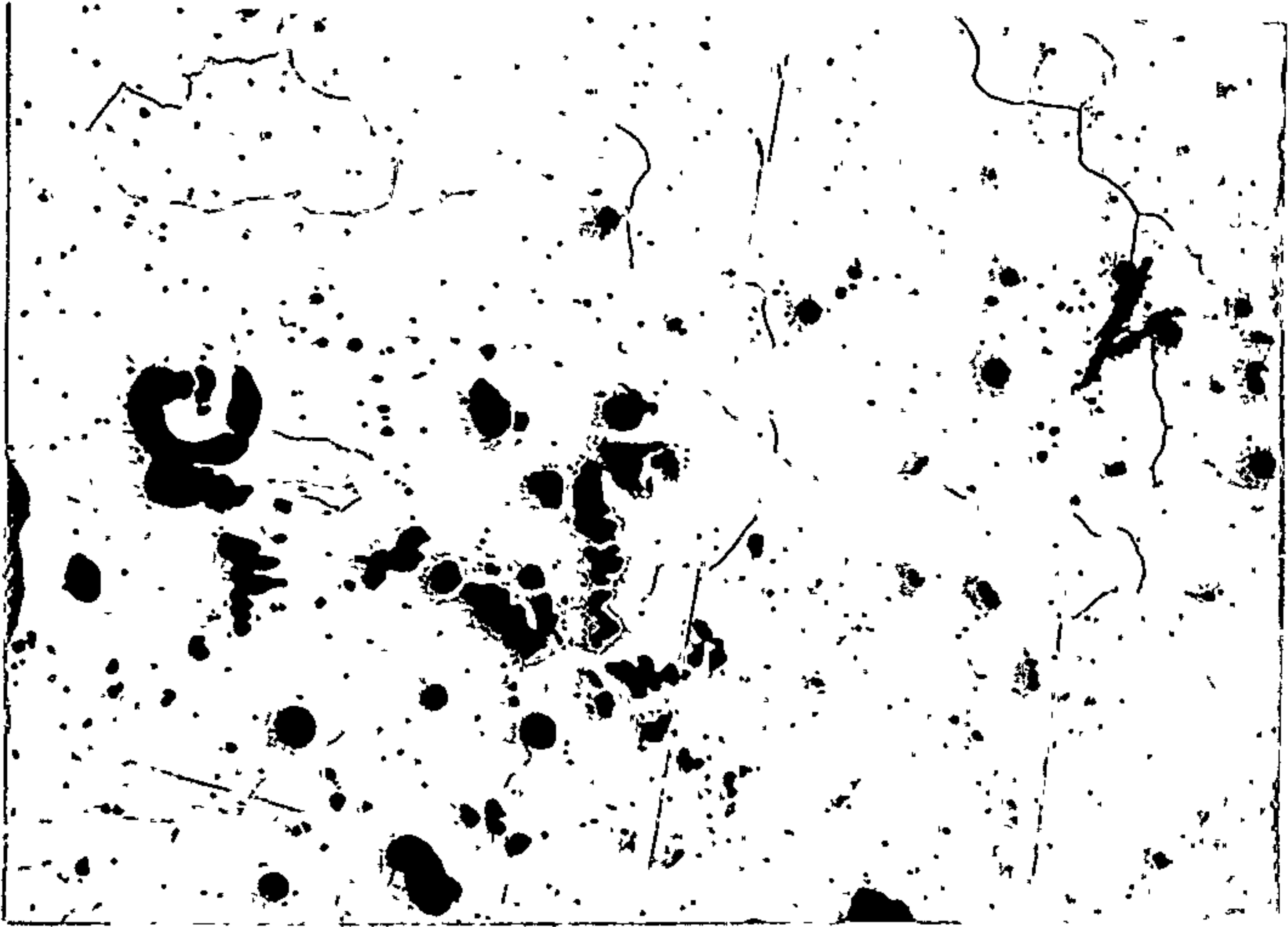
The previous results involving soldering variables have been illustrated using photomicrographs of Precious Metal C gold.

Similar results have been observed with Jelenko Firnilay, and figure 16 shows three typical photomicrographs of Firnilay showing a soldered joint where a gas-air blow pipe has been used, an electrically soldered joint and a soldered joint soldered electrically with a very small gap. In figure 16(a) and 16(b) one of each casting has been fully, dentally polished, the second casting being polished only to the sandpaper disk stage.

Where Firnilay was used and soldered with gas-air, complete alloying appeared to have taken place.

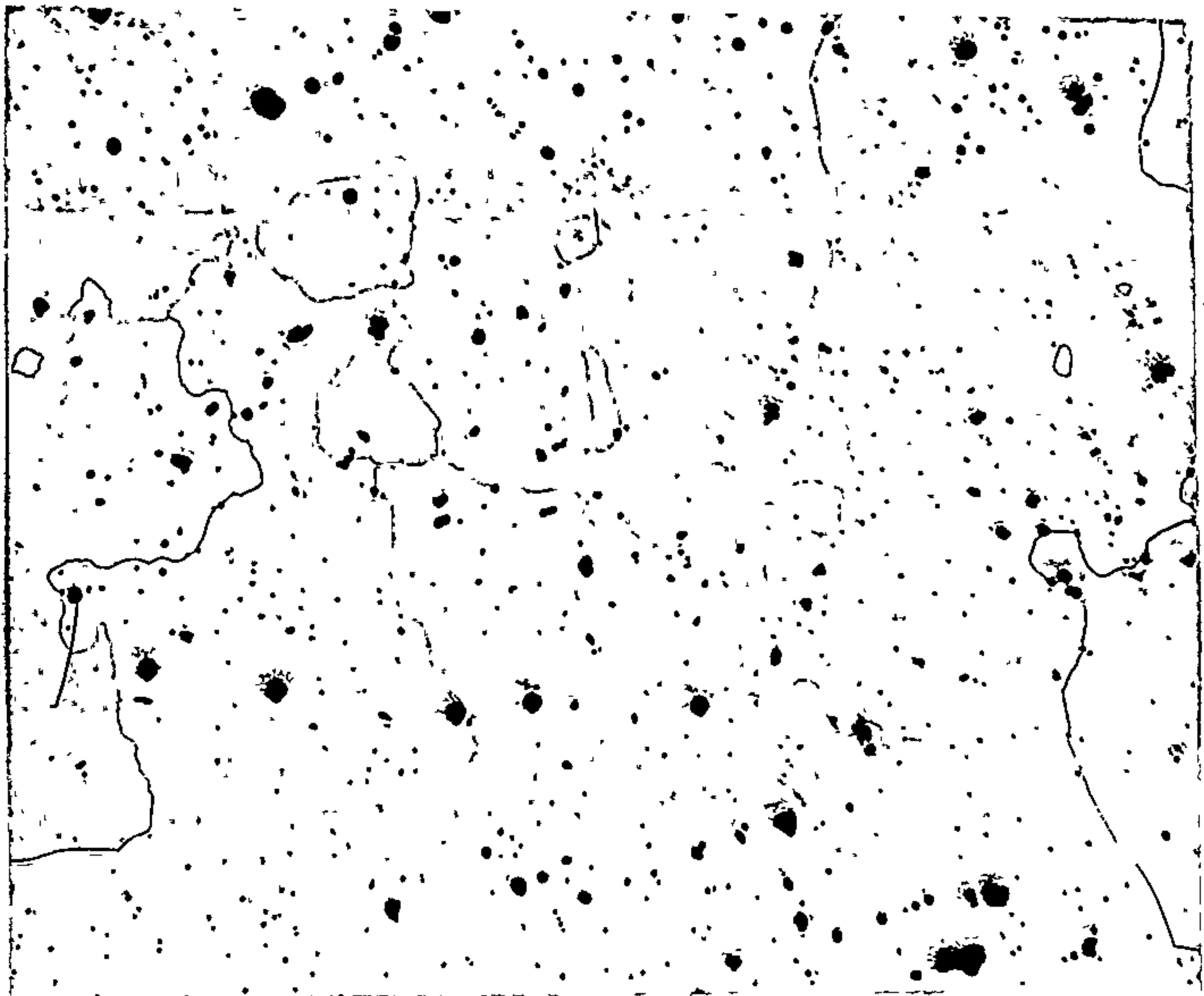
83a.

(a)



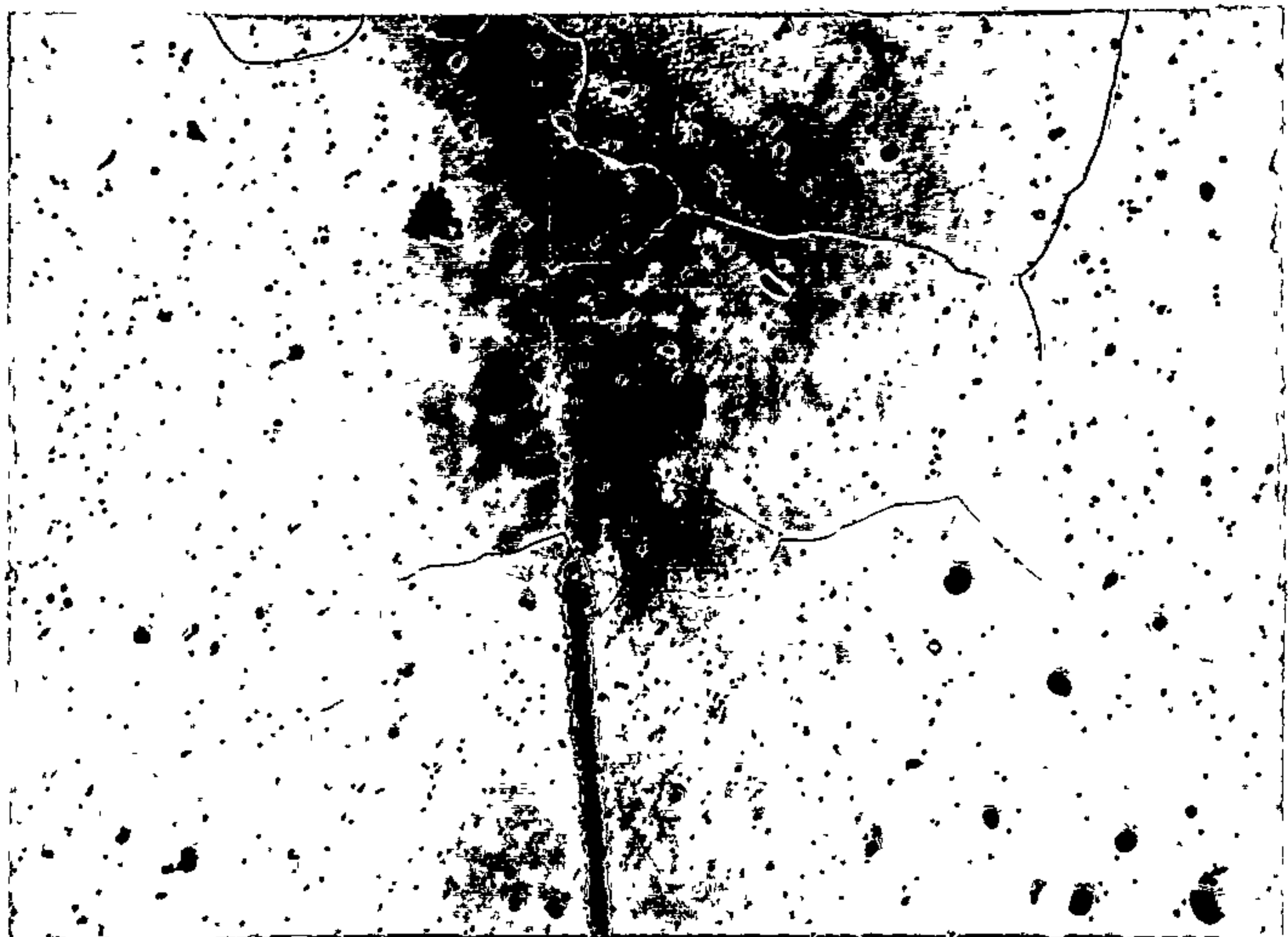
Gas-air
soldering.

(b)



Electric
soldering.

(c)



Electric
soldering,
very small gap.

Jelenko Firmilay X50.

Figure 16.

EFFECT OF SOLDERING AND HEAT TREATMENT ON PHYSICAL PROPERTIES.

Casting and Soldering.

Table V shows the effect of soldering on the hardness of casting gold alloys and gold solder. Table V gives results for castings made from Precious Metal C gold, soldered with 18K gold solder. Similar trends have been observed for other casting gold alloys.

Different methods of casting and soldering, did not produce hardness values that were significantly different at the 98 per cent confidence level. Although it has frequently been claimed that gold solder is harder and stronger than casting gold alloys, and table V produces mean values consistently higher for solder than for the parent alloy, the hardness values for solder are not significantly higher than for the castings when subjected to statistical analysis.

Heat Treatment.

Heat treatment was carried out on Precious Metal Type A, Type B, Type C casting golds, Jelenko Firmilay, Jelenko Modulay and 18K Gold Solder.

Table VI shows the hardness values of the alloys studied before and after heat treatment. It was found that

TABLE V.

Effect of Soldering on the Hardness of Casting Gold Alloy and
Gold Solder.

Specimen Type	Hardness (V.H.N.)	
	Gold Casting	Solder
<u>Non-Soldered:</u>		
Gas-air Cast	144 (4.7)	-
Thermotrol Cast	147 (5.5)	-
<u>Soldered (Gas-air with Flux):</u>		
Gas-air Cast	142 (11.3)	151 (4.2)
Thermotrol Cast	148 (10.5)	157 (6.0)
<u>Soldered (Electrically with Flux):</u>	153 (9.2)	156 (5.7)
<u>Soldered (Gas-air without Flux):</u>	146 (7.5)	157 (6.0)

TABLE VI.

The Effect of Heat Treatment on Casting Gold Alloys and Gold
Solder.

	HARDNESS (V.H.N.)					
	Casting Gold Alloy					18K. Gold Solder
	PRECIOUS METAL			JELENKO		
	A	B	C	Modulay	Firmilay	
As Cast or	85 (11.1)	117 (4.9)	143 (6.3)	118 (5.1)	153 (7.4)	
After Soldering						151 (7.0)
Softening Heat Treatment	67.4 (3.2)	116 (8.7)	138 (9.8)	129 (3.5)	154 (6.8)	134 (4.2)
Hardening Heat Treatment	66 (2.2)	111 (4.6)	165 (5.5)	123 (4.3)	158 (5.7)	164 (13.8)

Standard Deviations in Brackets.

Precious Metal A gold responded to softening heat treatment being considerably softer than in the as cast condition. This alloy did not respond to subsequent hardening heat treatment. Precious Metal B gold, Jelenko Firmilay and Jelenko Modulay did not significantly respond to softening or hardening heat treatment. Precious Metal C gold and 18K gold solder responded readily to heat treatments. Softening heat treatment produced only a slight reduction in hardness but hardening heat treatment produced a significant increase in hardness.

For Firmilay and Modulay the heat treatments used were, those previously described, as well as the slight variations recommended by the manufacturer.

While it is not surprising that Precious Metal A and B golds, and Modulay, show little response to heat treatments, it is somewhat surprising that Firmilay was not more amenable to these processes.

Heat treatment had no effect on the grain structures of the gold alloys studied. This is shown in the next series of photomicrographs, figures 17, 18 and 19. The castings subjected to study were from the same specimen and in the as cast state, after softening heat treatment and after hardening heat treatment.

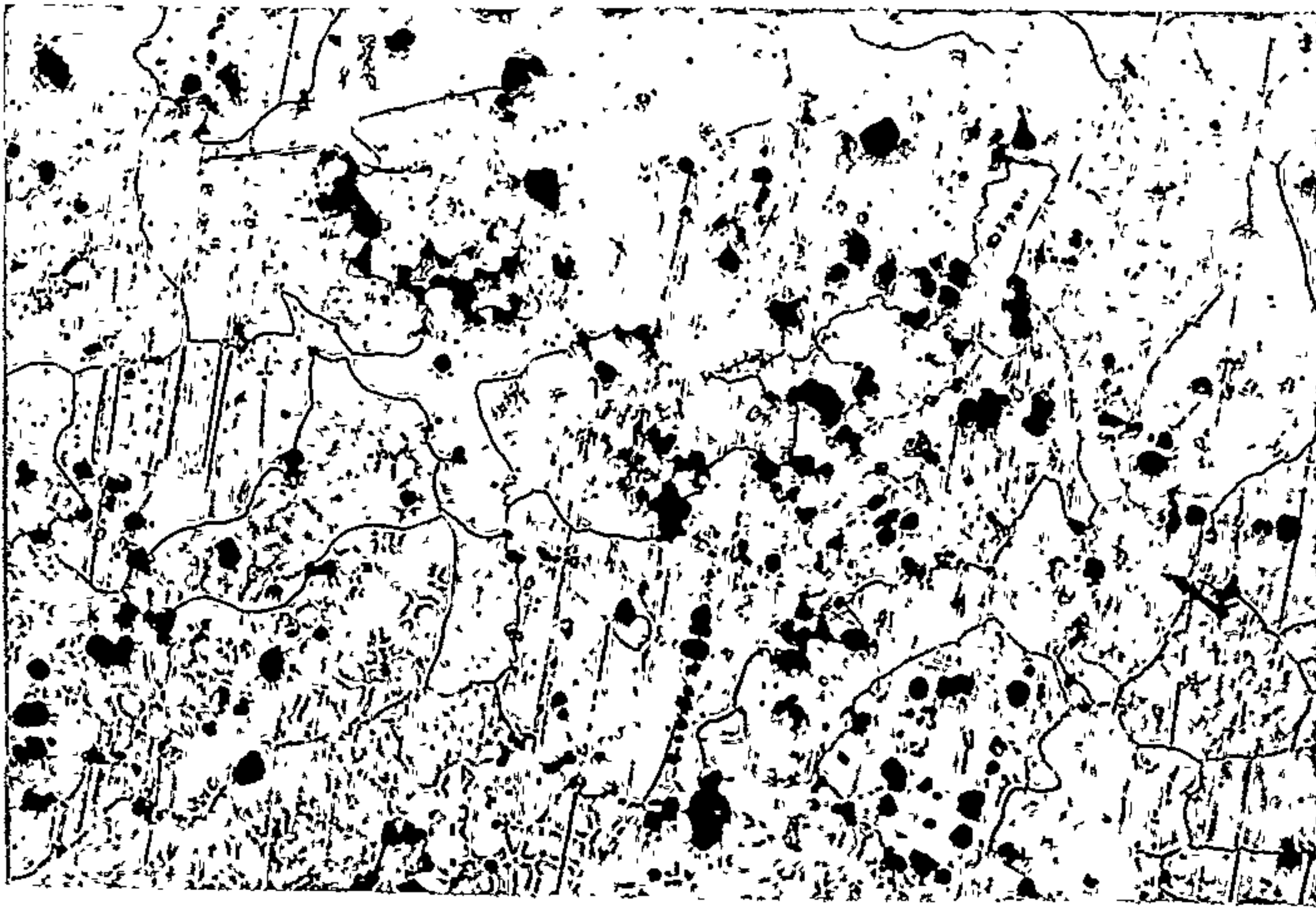
The grain size was approximately the same, in each of the three conditions, for each specimen, showing that although

(a)



As cast.

(b)



Softened.

(c)

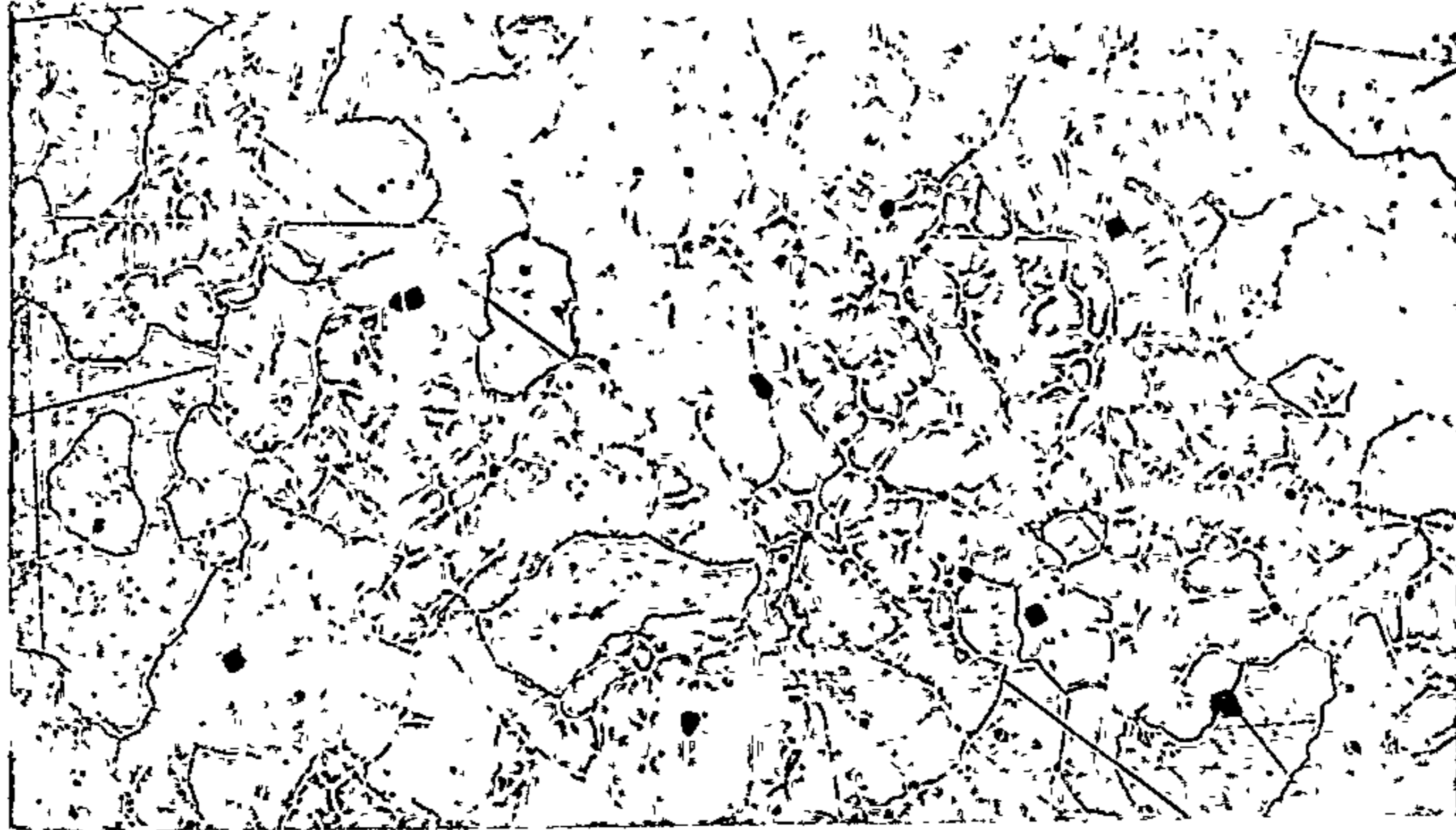


Hardened.

Precious Metal C Gold.
(gas-air castings).
X50.

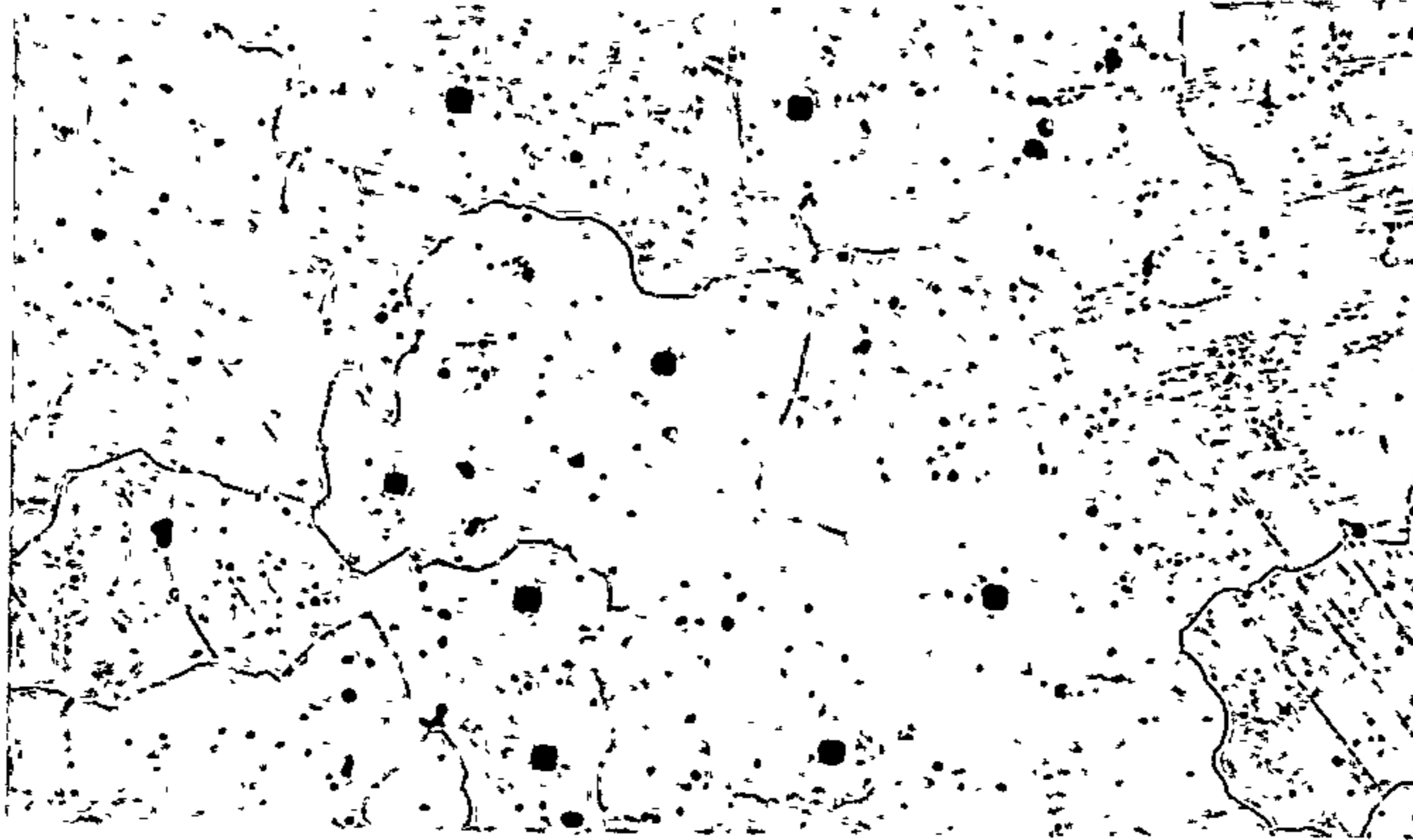
Figure 17.

(a)



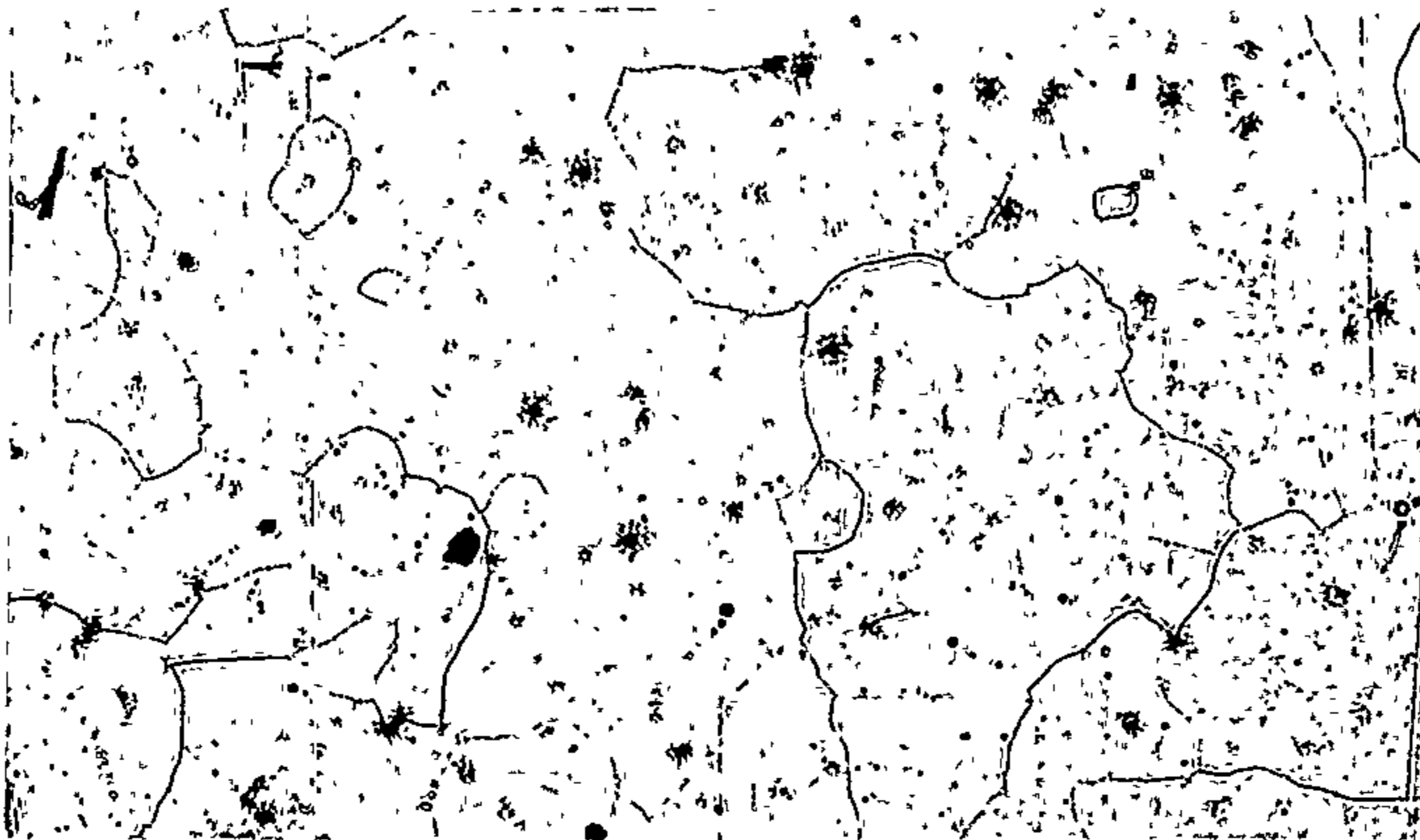
As cast.

(b)



Softened.

(c)



Hardened.

Precious Metal C Gold - Thermotrol Castings.
X50.

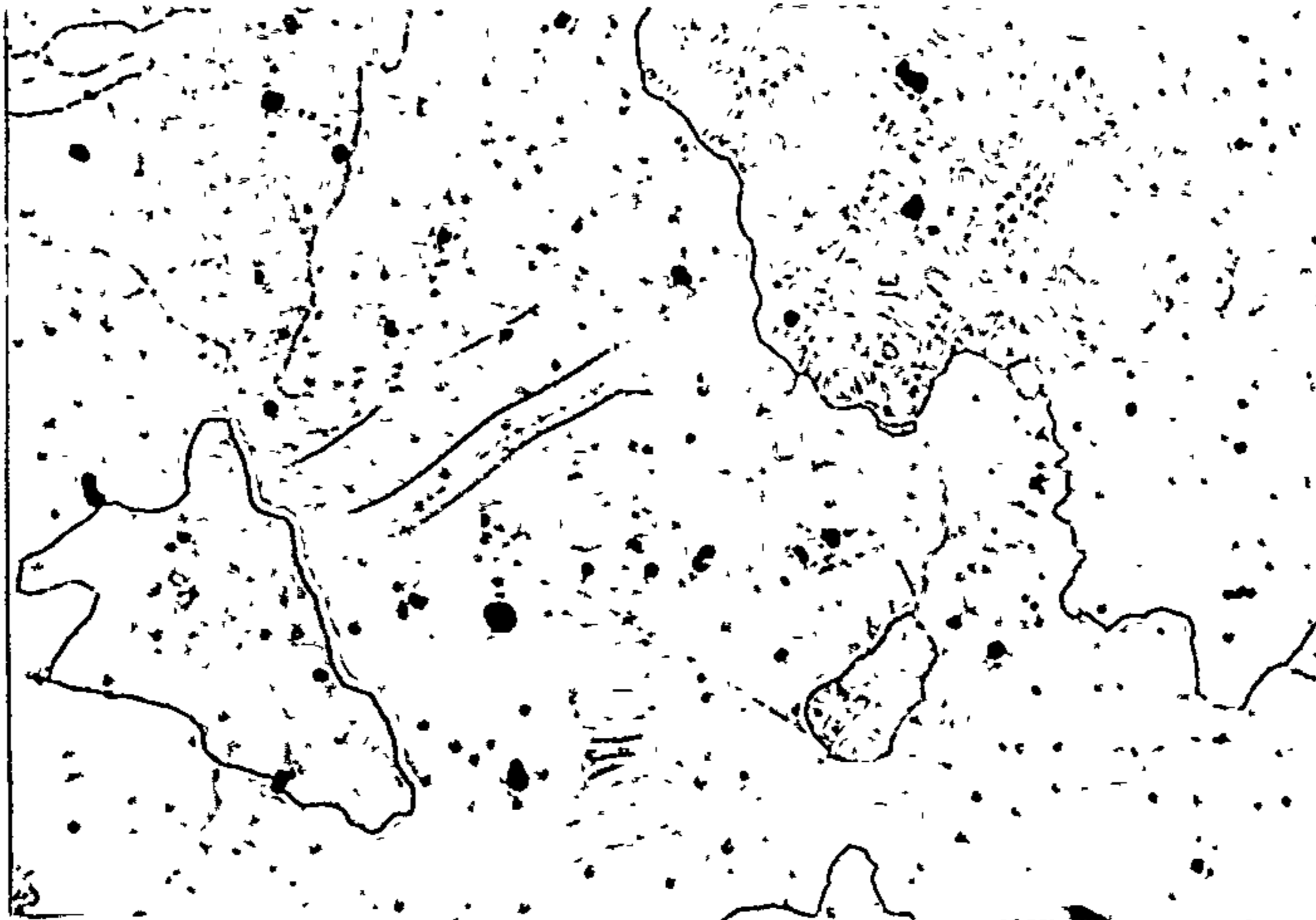
Figure 18.

(a)



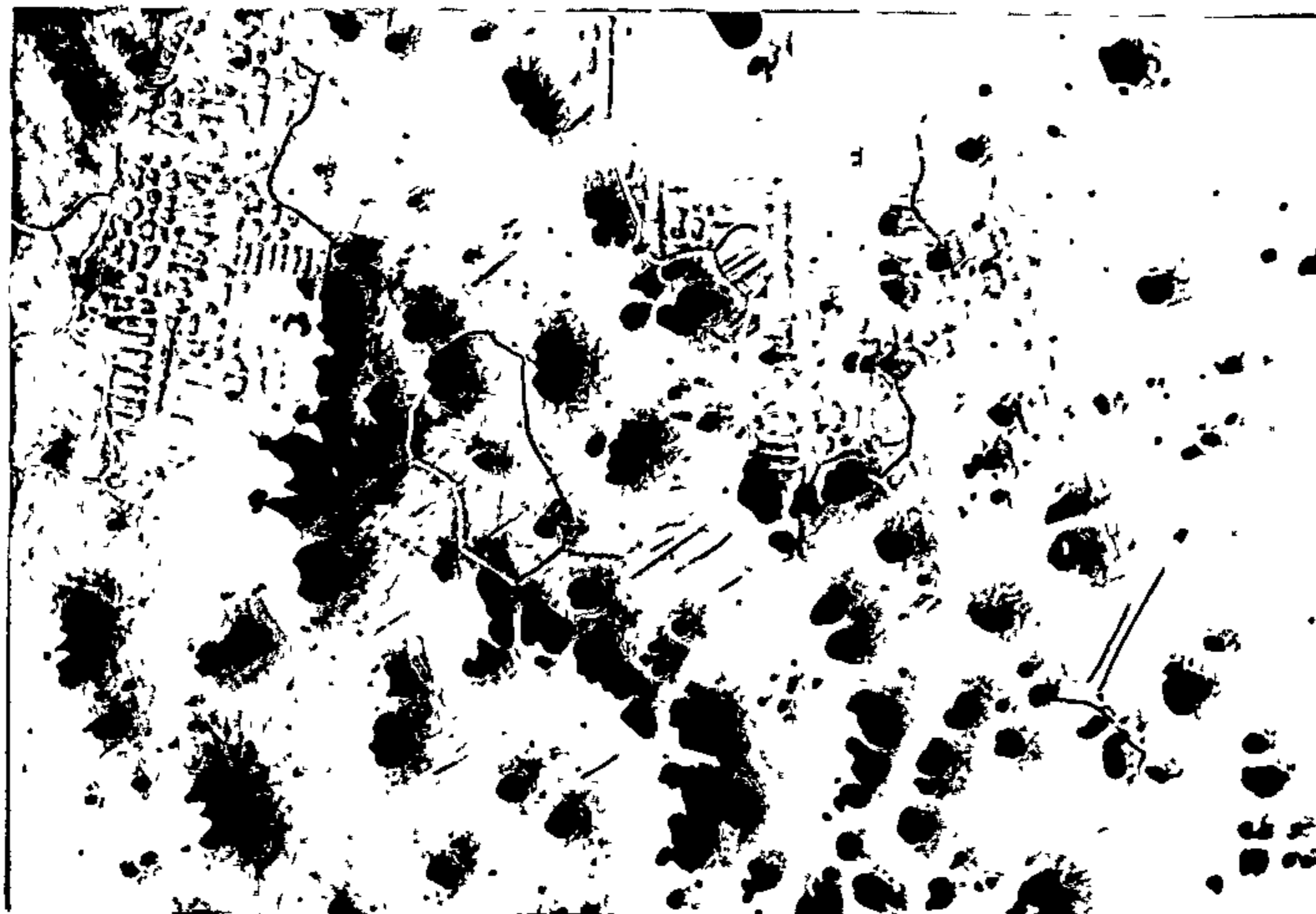
As cast.

(b)



Softened.

(c)



Hardened.

Jelenko Firmitay X50.

Figure 19.

grain growth occurs very readily during soldering, no change in structure occurs during heat treatment. It has been pointed out previously that changes in hardness are almost certainly due to order-disorder reactions taking place in the gold-copper system.

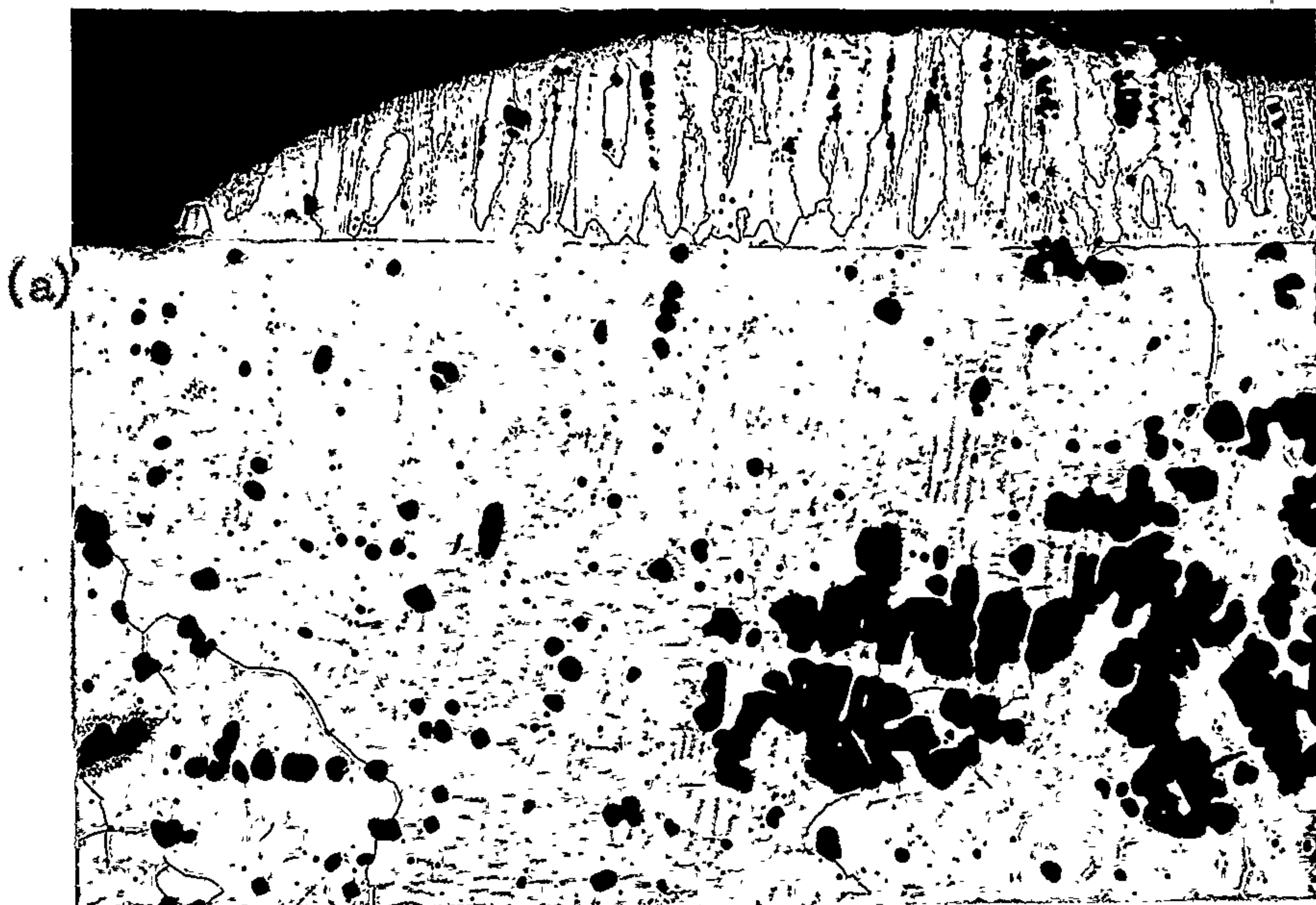
CONTACT POINT SOLDERING.

The soldering of contact points on gold castings is frequently carried out in restorative dentistry. The most frequent method of carrying out this type of soldering operation is freehand, using a bunsen flame, making use of a vaseline based flux, and an antifix such as "pencil lead" or a colloidal graphite such as Aquadag*.

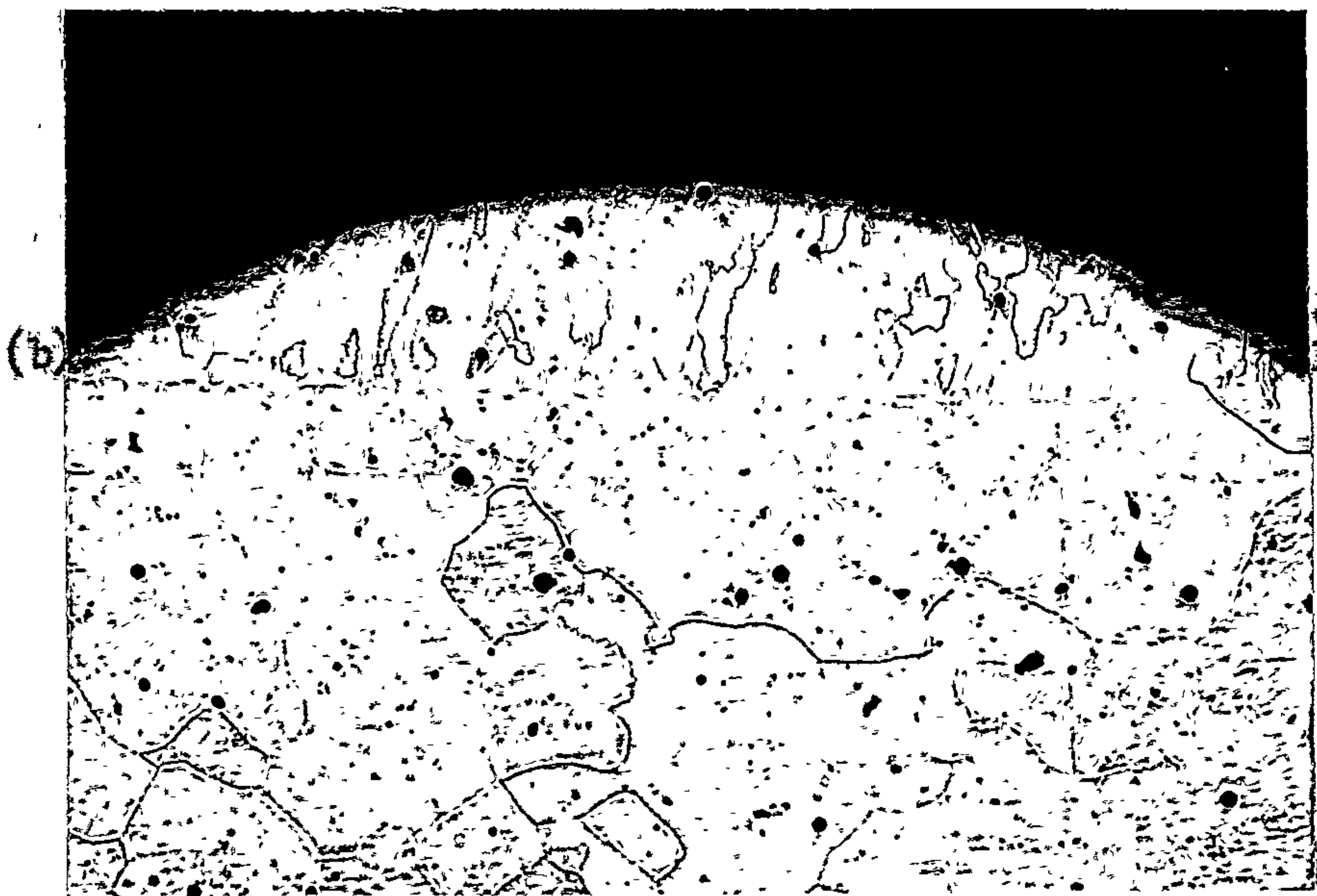
Typical photomicrographs of contact point soldering are shown in figure 20. In figure 20(a) Precious Metal 6 gold, there is apparent lack of alloying. The grains in the gold solder run at right angles to the surface of the casting, being columnar in form. There appears to be continuity of the grain boundary across the soldered joint in the region of A. The parent alloy in figure 20(a) is principally made up by a large grain of diameter approximately 2,000 microns. In figure 20(b) Jelenko Firmilay, there appears to have been alloying between the solder and the gold casting, although the grain structure in the solder is quite different from that of the parent alloy.

There appears to be a relationship between the porosity.

* Acheson Colloids Limited, Plymouth, Devon, U.K.



Precious
Metal
C Gold.



Jelenko
Firmily.

Contact Point Soldering - Thermotrol Cast X50.

Figure 20.

in the original casting and the soldered contact point.

Hardness determinations have shown that in most cases of contact point soldering, the hardness of the solder was slightly higher than the hardness of solder in investment. It is doubtful however if this is a significant difference.

TENSILE TESTS.

A limited study of tensile testing, of Precious Metal C gold alloy, was carried out for the purposes of establishing data in an attempt to compare strengths that may be expected in a one piece casting or a typical soldered joint restoration, and to attempt to establish a relationship between hardness (V.H.N.) and ultimate strength. All castings used in this study were made in the Thermotrol casting machine.

Tensile tests were performed on castings in the "as cast" state, after hardening heat treatment, after softening heat treatment and on specimens which had been formed by soldering two halves of the dumbbell shaped specimen.

The results of testing ultimate tensile strength, and hardness values obtained after the tensile test, are shown in table VII and figure 21. Figure 21 shows the relationship between ultimate tensile strength and hardness (V.H.N.) for cast specimens and soldered specimens. From the straight line nature of these graphs it is apparent that a constant relationship exists between these two properties for castings or soldered joints. The relationship, although constant for casting gold alloy or gold solder, differs for the two materials.

From table VII it can be seen that the variation in hardness, which occurs with hardening and softening heat

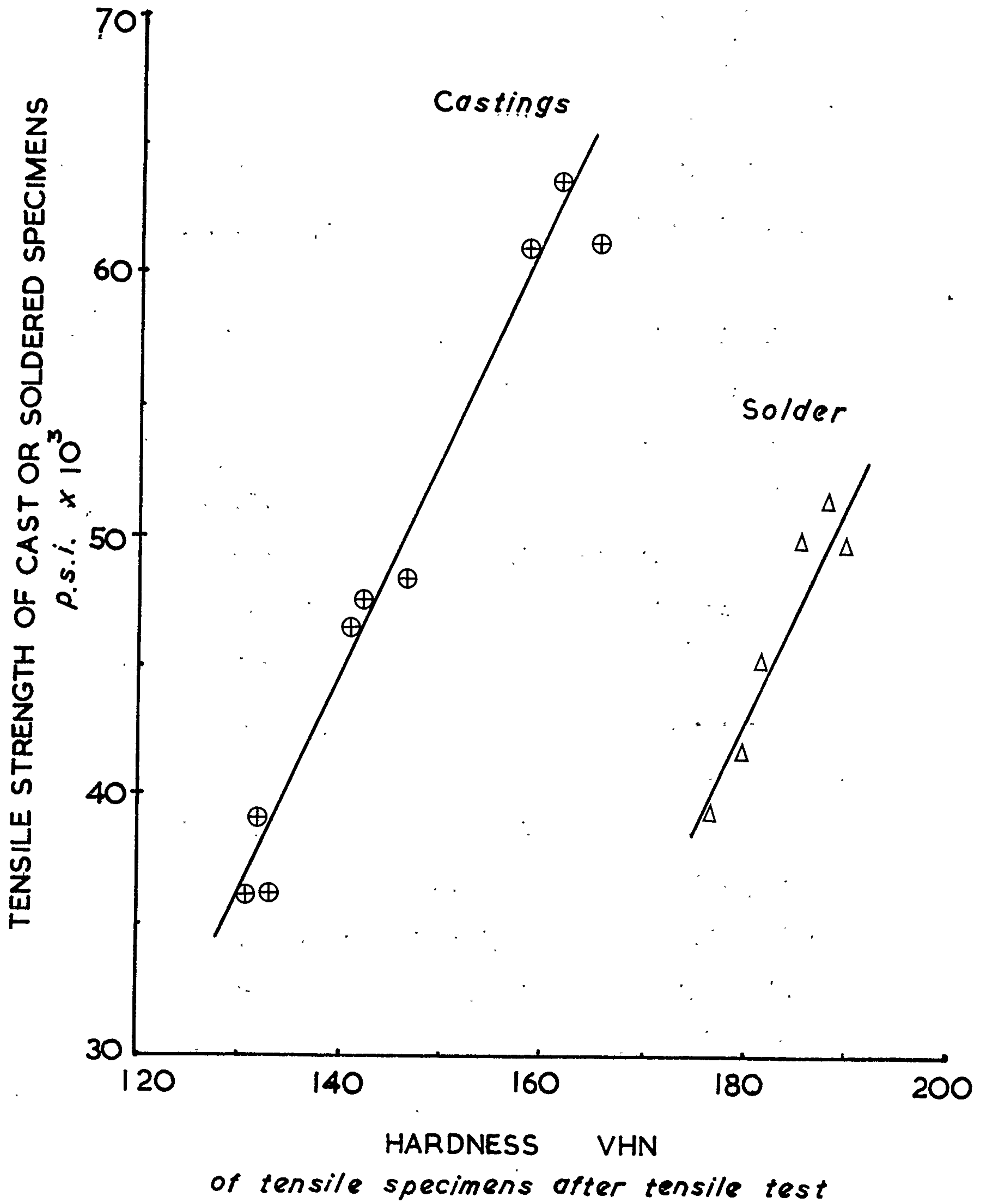


Figure 21

TABLE VII.

Relationship between Vicker's Hardness Number and ultimate tensile strength for "Precious Metal 'C' Gold" and 18K gold solder.

Casting (Thermotrol)	Ultimate Tensile Strength (p.s.i.)	Hardness (V.H.N.)*	
		Casting	Solder
<u>NOT SOLDERED</u>			
As Cast	47,000 (1,700)	143 (4.6)	
Softened	37,000 (1,400)	133 (3.8)	
Hardened	61,000 (2,300)	160 (5.3)	
Soldered Gas-air (as soldered)	49,000 (2,000)	176 (7.9)	186 (9.6)
Soldered Electric (as soldered)	45,000 (1,600)	150 (6.5)	183 (9.2)

Standard Deviations in Brackets.

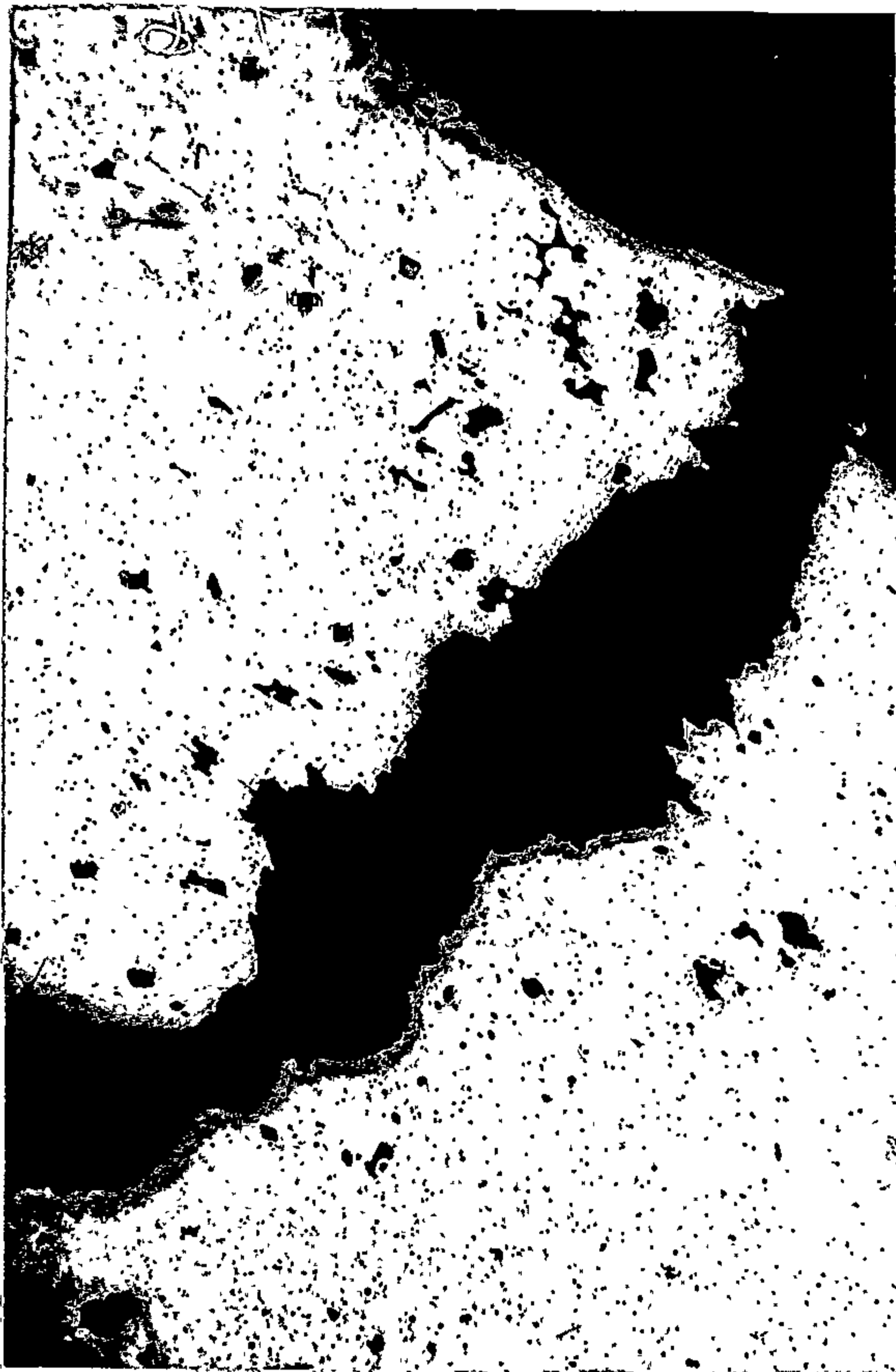
* All values are means of three specimens, for this study.

treatments, is reflected in the ultimate tensile strength of the casting. The ultimate tensile strength achieved by a one piece casting in the as cast condition is not significantly different from the ultimate tensile strength of specimens formed by soldering either by a gas-air blow pipe or electrically. There is no evidence that apparent lack of alloying as seen in gas-air soldering produces weaker soldered joints than electric soldering which produces complete alloying. Nor is the reverse situation seen to apply.

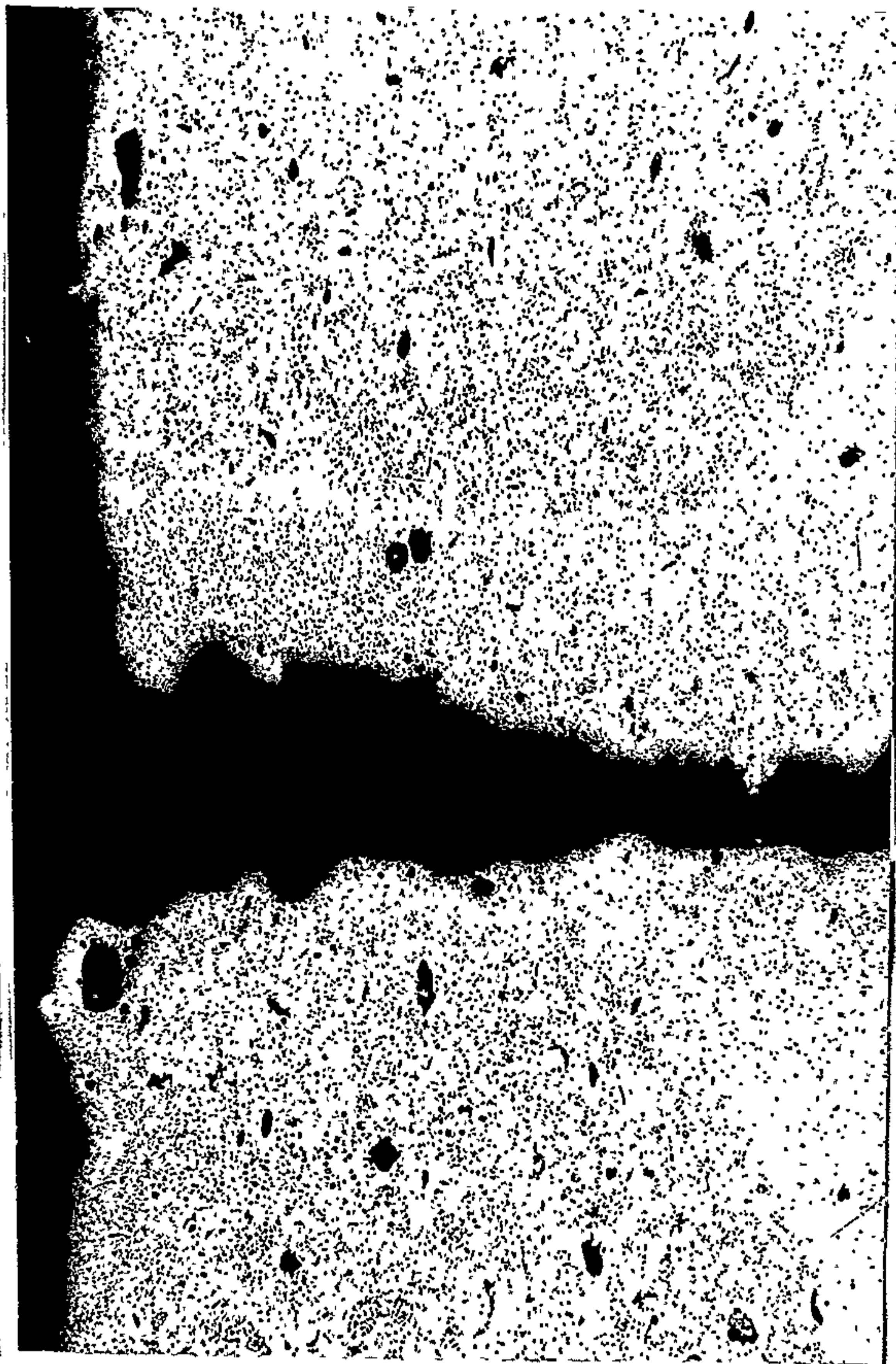
Some typical fractured specimens are shown in figure 22. In these photomicrographs can be seen the relationship of the fracture line and the parent alloy. In most specimens, fracture occurred through the solder itself, as seen in figure 22(a) and 22(b). Some specimens fractured through both parent alloy and solder, as seen in figure 22(c). In no specimen did fracture occur by solder pulling away from the parent alloy.

From the data obtained, it was observed that the ultimate tensile strength of Precious Metal C type casting gold alloy, was lower than the data supplied by the manufacturer.

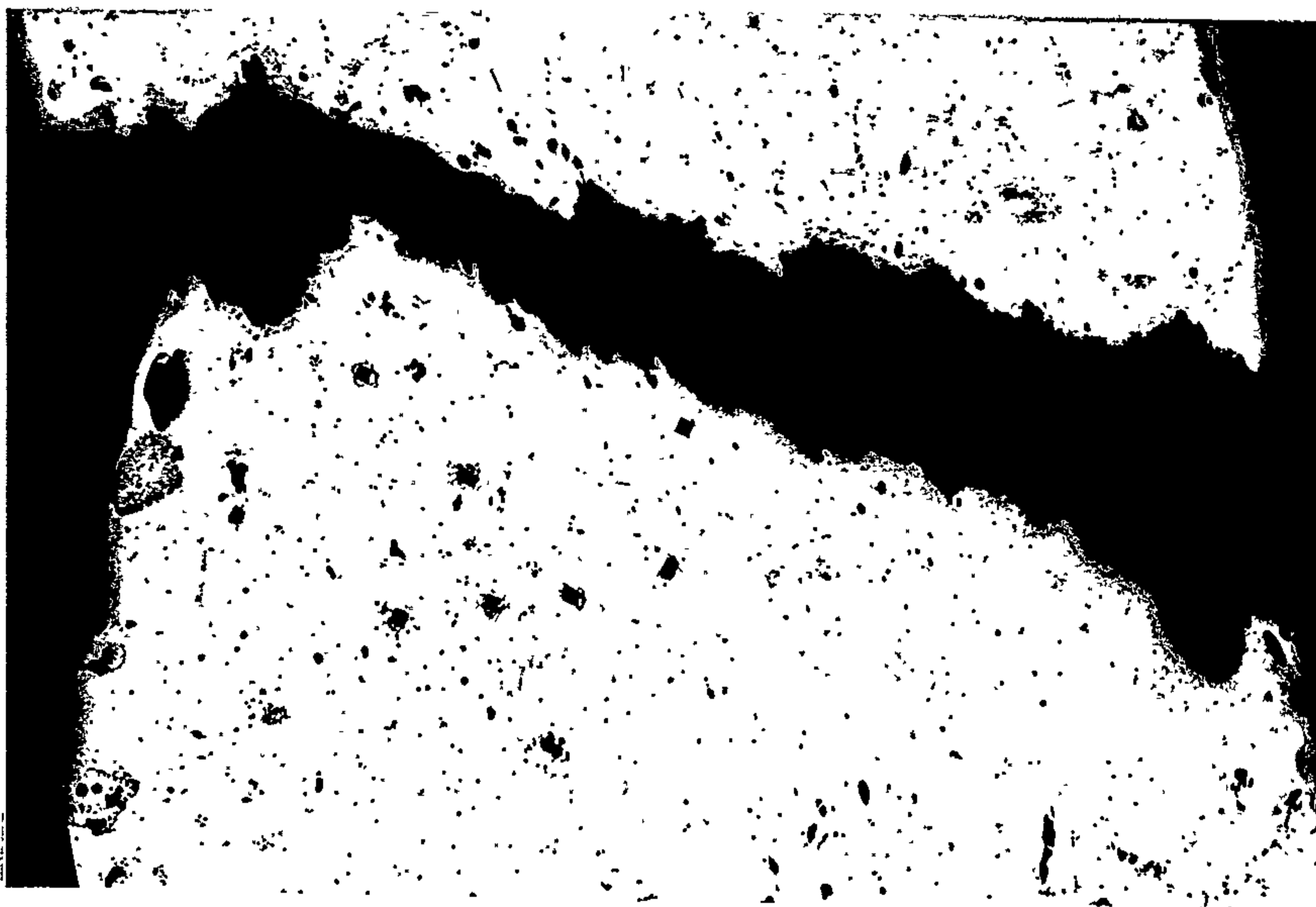
A typical stress strain curve for Precious Metal C type casting gold alloy is shown in figure 23. This stress strain curve was typical of those obtained during the testing of new Precious Metal C gold, cast in a Thermotrol and tested in the as cast condition.



(a)



(b)



(c)

Tensile Tests X50.

Figure 22.

93b.

STRESS STRAIN CURVE

Thermotrol As Cast

Gauge Length 6 mm.

Diameter 2.983 mm.

Cross Section Area 0.17 sq. in.

$\frac{1}{92.1}$ sq. in.

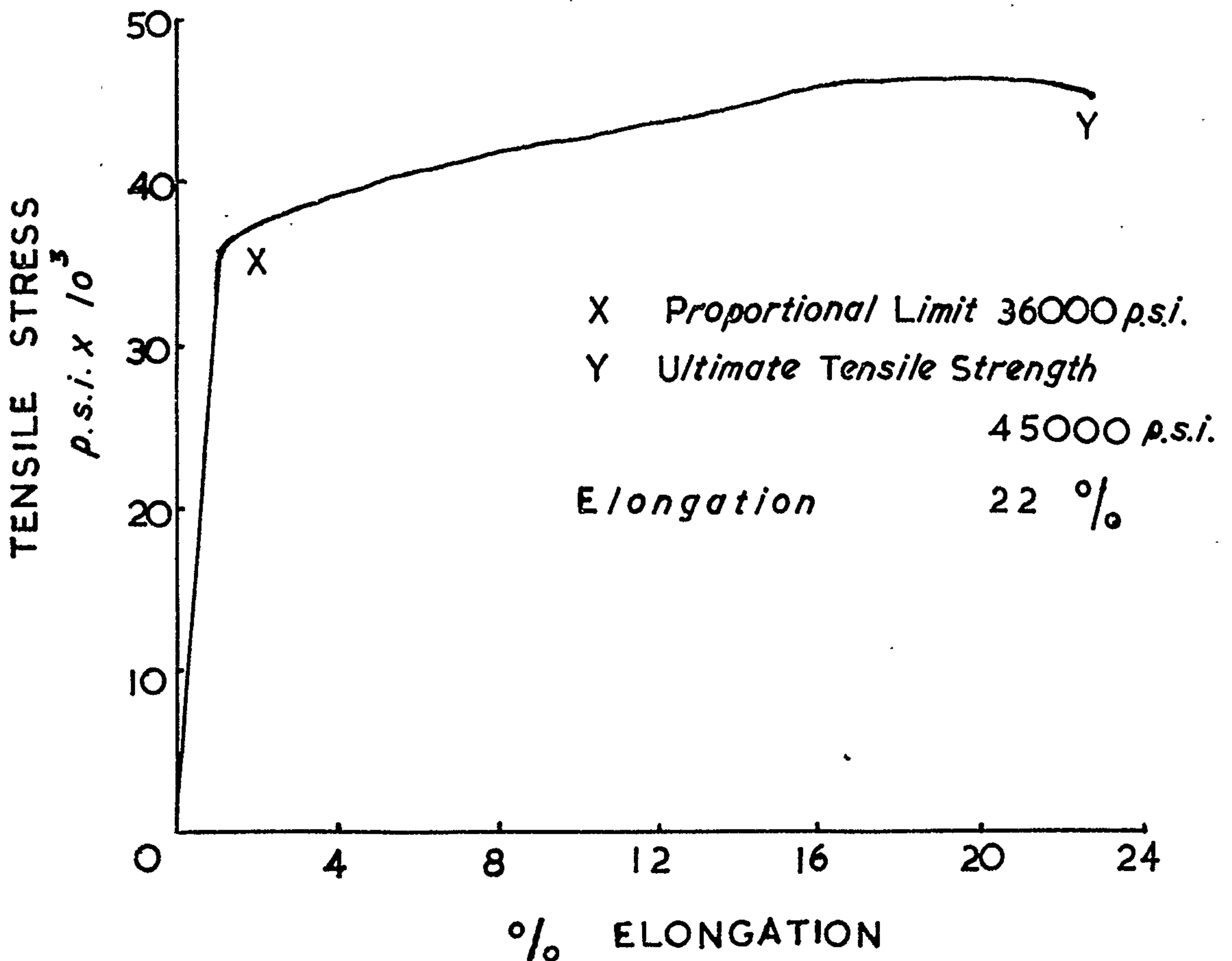


Figure 23

BEND TESTS.

It has been observed, in the study of all metallographically prepared specimens of gas-air soldering, and contact point soldering over an open Bunsen flame, that an apparent lack of alloying occurs between parent alloys and gold solder. This lack of alloying did not occur where soldering had been carried out electrically. In electric soldering it was observed that, although the gold solder could be clearly discerned, no vacancies were apparent between gold alloy and gold solder.

To study the nature of the bond between parent alloy and gold solder, the previously described (page 67) bend test was used.

After bending soldered specimens through an angle of approximately 10 degrees, for twenty or thirty bends, it was observed that no failures of the soldered joint occurred. There was no tendency for the gold solder to pull away from the parent metal. Deflections of 10 degrees were used since this exceeds the maximum deflection, likely to occur clinically in bridge work.

Slip planes were observed after the first deflection and slip increased with increased bending.

Figure 24 shows the slip planes occurring at different

stages of bending in an electrically soldered joint, unetched.

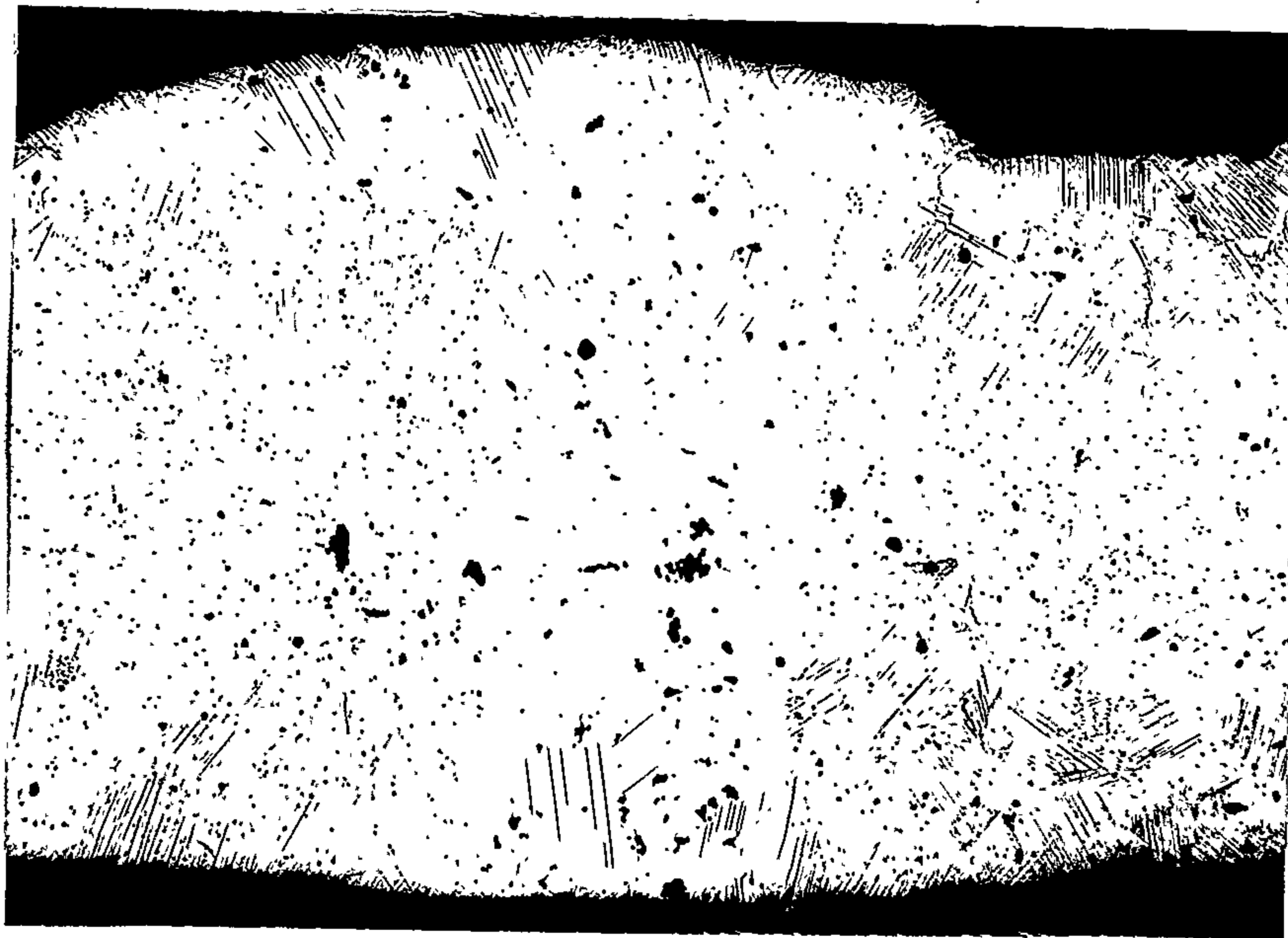
Figure 24(a) shows the specimen before bending, while (b), (c) and (d) showed the specimen after one bend, two bends and twenty bends respectively. Slip planes can be seen in castings and gold solder and some are continuous within grains, across the soldered joint, indicating that true alloying has taken place. Although unetched, the shape of different grains may be readily discerned by the change of direction of the slip planes.

Observations were also made on etched specimens, and figure 25 shows the results of bending on an electrically soldered joint. Figure 25(a) shows the electrically soldered joint before bending, and figure 25(b) shows the same joint after some bending.

95a.



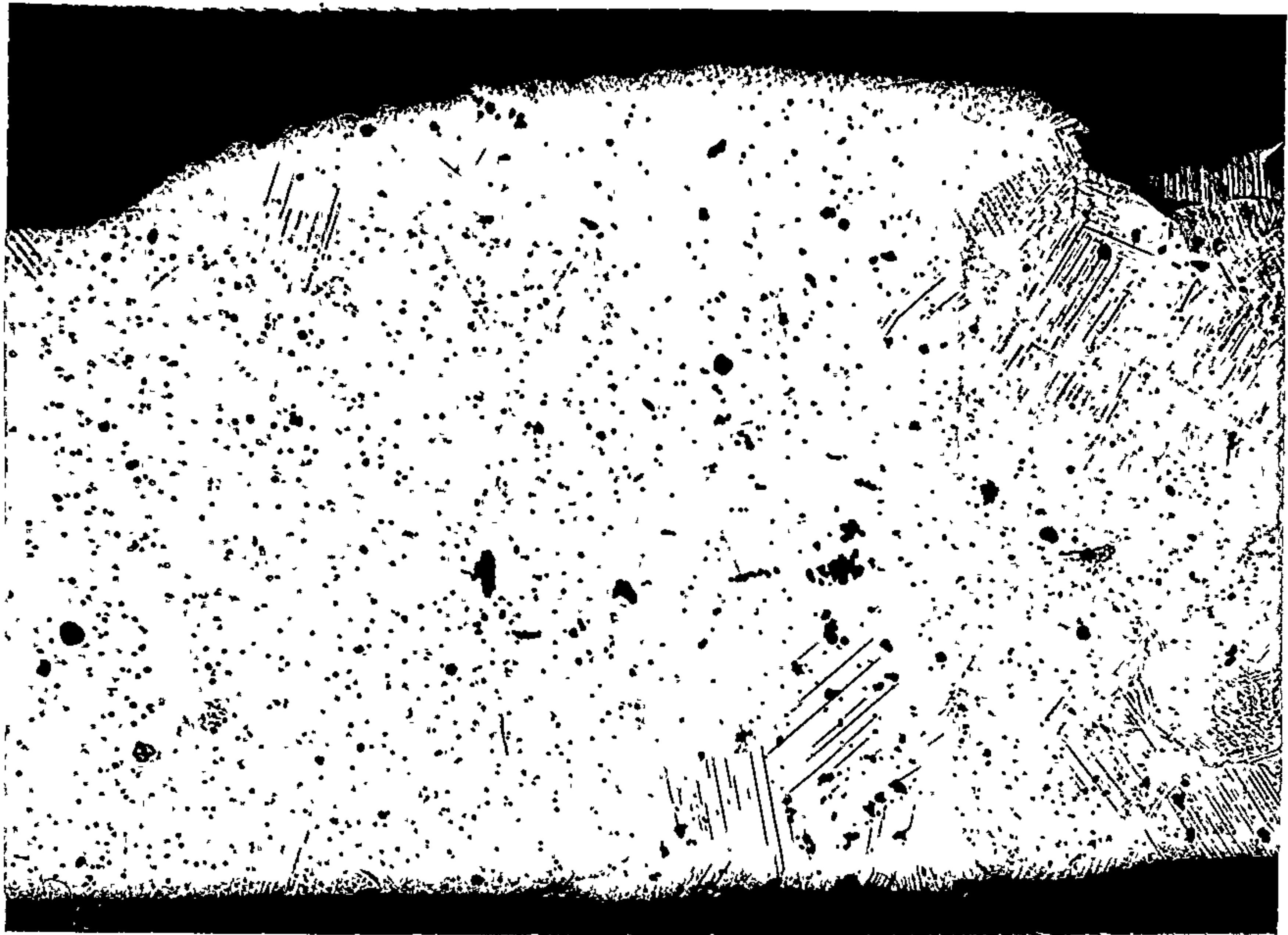
(a)



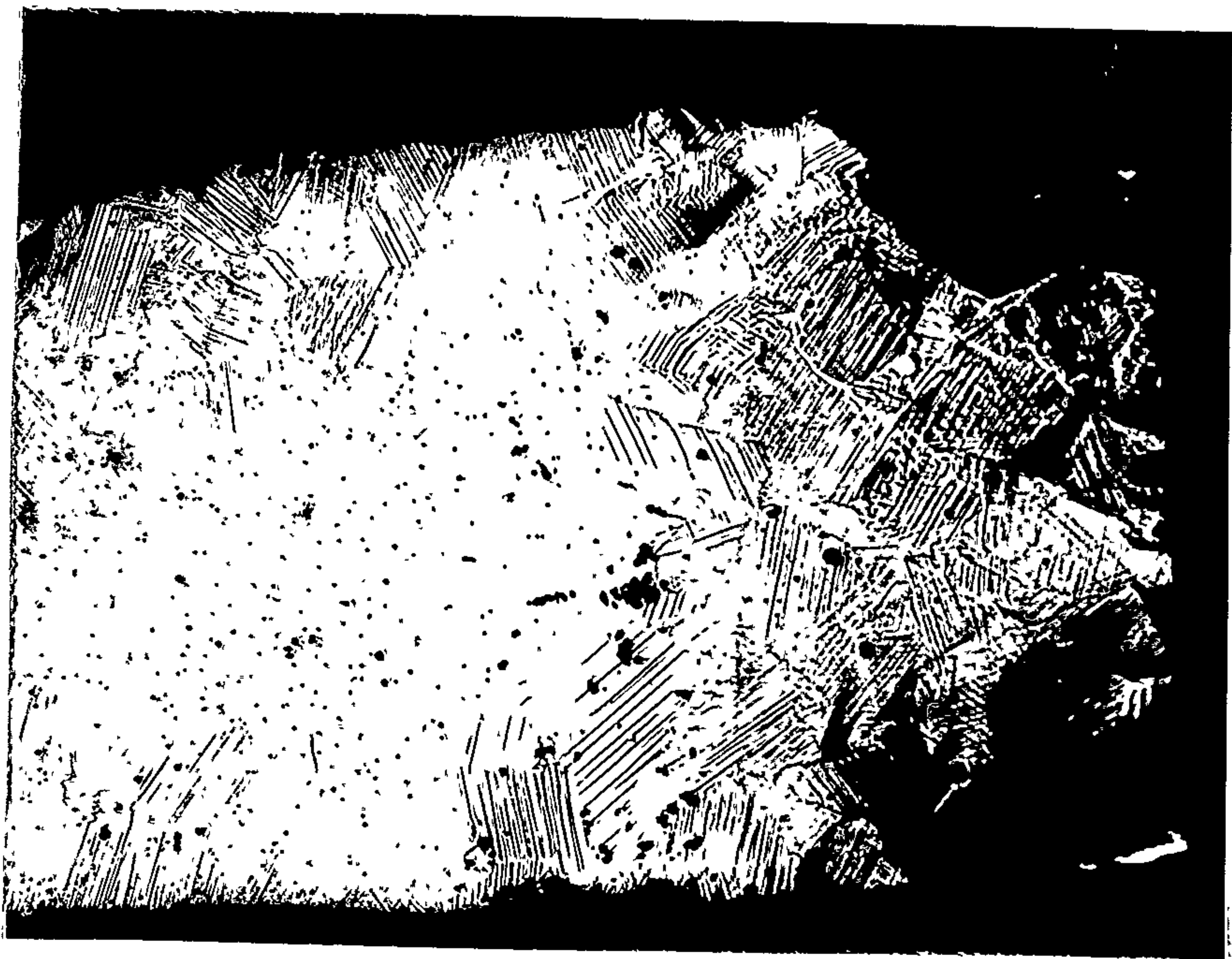
(b)

Bend Test
X50.
Figure 24.

95b.



(c)



(a)

X50.

Figure 24.

95c.



(a) Before Bending.



(b) After some Bending.

Bend Test - Electrically Soldered - X50.

Figure 25.

Figure 26 shows photomicrographs X50 of a gas-air soldered joint, before and after bending. From figure 26(a) an apparent lack of alloying can be clearly seen, between the solder and the castings. Figure 26(b), a photomicrograph after five bends, shows no tendency to fracture at the soldered joint. Slip planes can be seen in figure 26(b) in both parent alloy and solder. Some slip planes can be seen to cross the solder-casting junction. Regions X and Y were studied at a magnification of 1000X and photomicrographs of these areas are seen in figure 27.

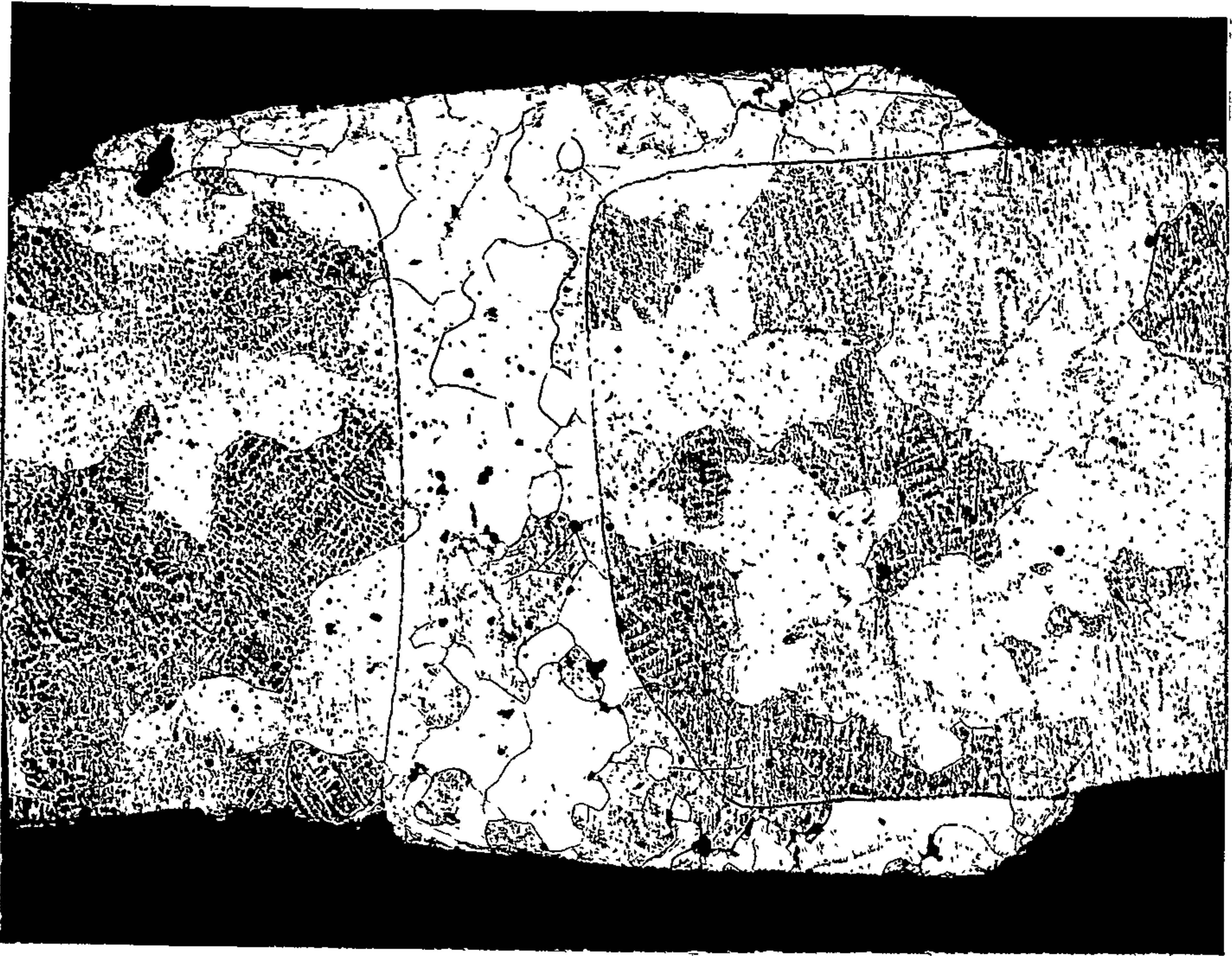
Figure 27(a) shows, quite clearly, slip planes crossing the junction between the gold solder and gold casting in region X. The different directions of slip planes in different grains may be seen.

Figure 27(b) shows a similar situation in region Y.

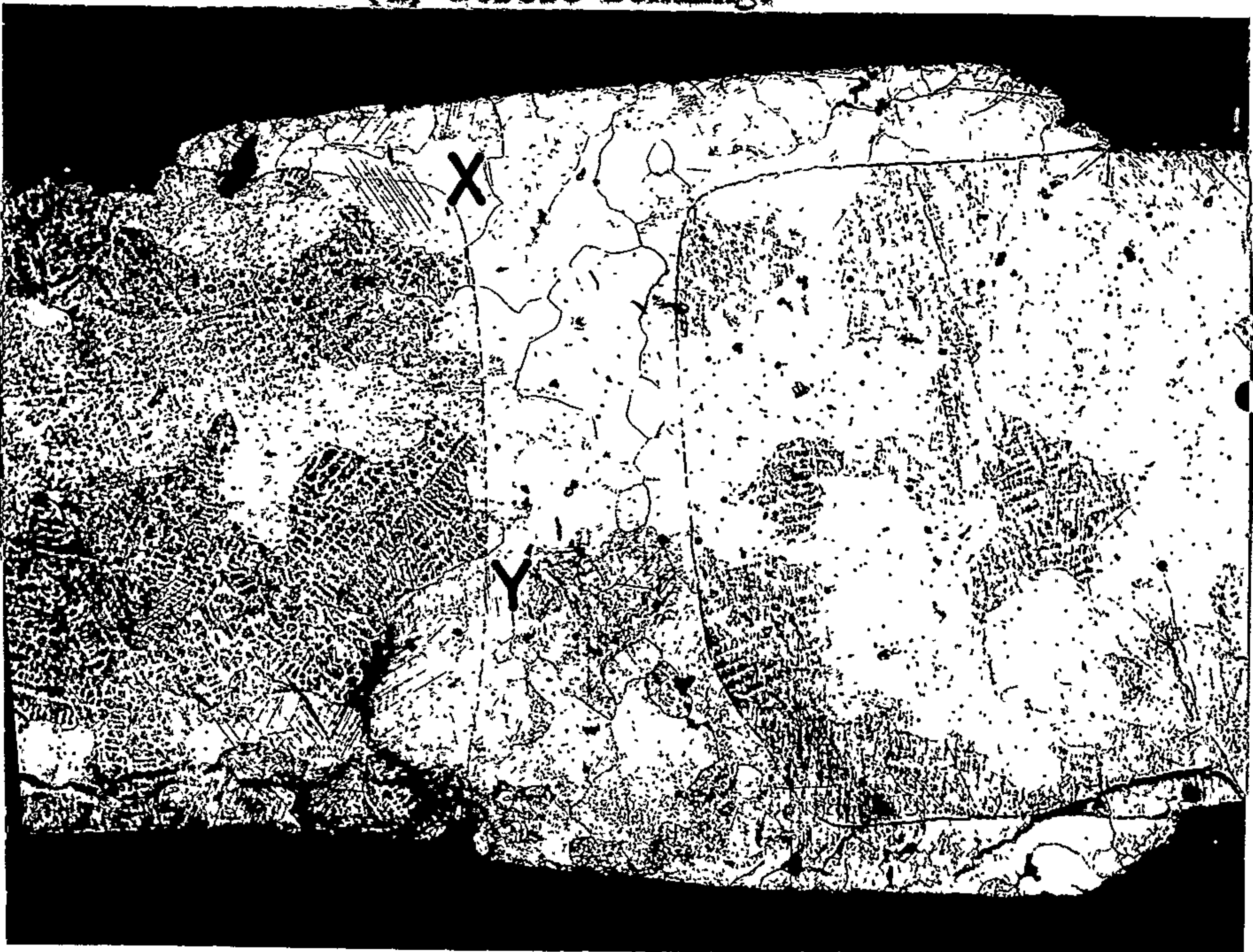
Figure 27 shows quite clearly that there is no real lack of alloying between the solder and the parent alloy. The apparent dark space, at the junction, seen at low magnifications is not continuous, but is an accentuation of the arms of the dendrites. This is particularly evident in figure 27(b). This structure arises because of lack of time for equilibrium to be reached after solidification.

Careful study of gas-air soldered joints at high power (X1000) reveals that although the grain size in the solder is smaller than that in the parent alloy, there is continuity of grain boundaries across the soldered joint, as seen in figure 27(b), in some areas.

96a.



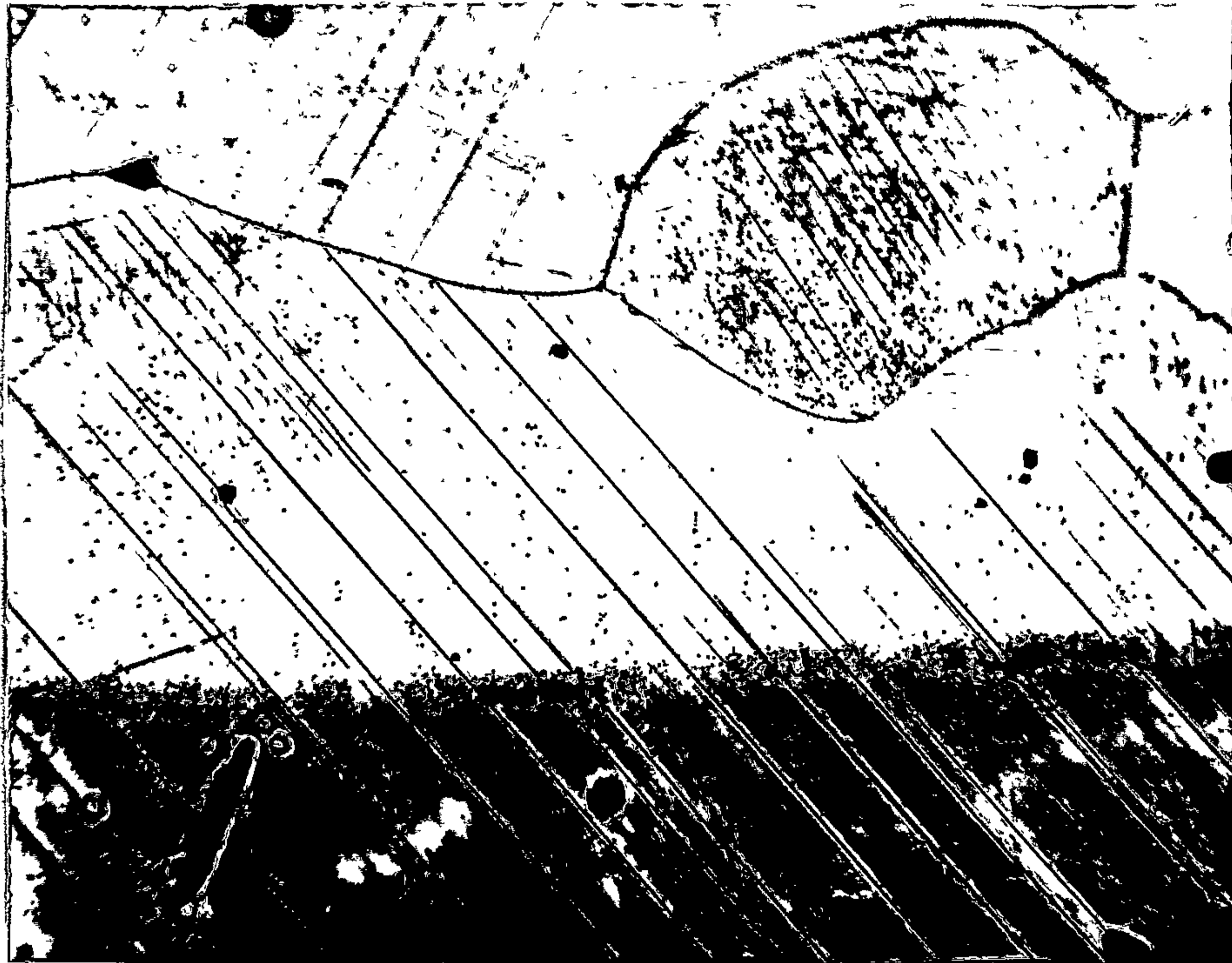
(a) Before Bending.



(b) After Bending.

Bend Test - Gas-air Soldering - X50.

Figure 26.



X1000.

Figure 27(a).

96c.



X1000.

Figure 27(b).

CONCLUSIONS AND DISCUSSION.

Following the original investigation of dental casting gold alloys and gold soldering operations involving cast structures it is possible to draw conclusions, relative to these operations. Although some of these conclusions are supportive of past investigations, many of the findings are diametrically opposed to some of these past investigations.

Despite every effort to cast dental gold alloys, using the methods normally employed in the practice of dentistry, and with close adherence to correct technique, porosity was found to be present in all gold castings. Porosity tended to be found within the body of the casting rather than close to surfaces. Where proper technique was employed it was rare to find voids within a casting greater than 50 - 60 microns, in diameter. In general, voids tended to be irregularly shaped. Voids 60 microns in diameter, where irregularly spaced, would not influence the surface of a casting clinically.

Voids which occur as large inclusions trapped in the arms of dendritic structure, as seen in figure 2(b), may cause clinical problems, since if uncovered during polishing, remain as a surface defect despite continued polishing. The degree of porosity exhibited in the photomicrographs in this study can probably be considered as the normal porosity in good dental

castings. These photomicrographs are selected from approximately 200 castings and soldered joints which have been sectioned.

The sprue size used in this study appeared to be adequate, as castings involving the casting of two joined class II inlays exhibited only the same level of porosity as single class II inlay castings.

The re-use of casting gold alloys has no effect on the physical properties or microstructure of these alloys. In figure 2 it is obvious that where gold alloy has been re-used ten times, the degree of porosity is not significantly different from a casting made using only new gold. The use of some new gold did not appear to improve the physical properties or reduce the porosity in a casting. It is possible, however, that where casting is performed with less care than usual, and excessive overheating or oxidation takes place, lower melting point elements may be volatilized. Zinc, present for its scavenging effects, has a boiling point of 906°C and could easily be removed.

Different methods of casting dental gold alloys have been found to produce castings which are not significantly different in terms of porosity, or hardness and consequently ultimate tensile strength. Although the use of the Thermotrol or gas-air centrifugal casting machines does not produce

significantly better results than the hand swinger, the advantages of both of these are obvious in terms of consistency in the hands of large numbers of operators.

The difference between cast gold alloys and gold solder in the form as supplied by the manufacturer and after casting or melting, has been demonstrated. That the same hardness and hence tensile strength as supplied cannot be achieved after casting is of no importance. It would be extremely unusual if the strength and hardness of a cast material were as great as these properties in a wrought material.

It has been demonstrated that for the same casting gold alloy, a smaller grain size is achieved in castings made using gas-air casting methods than the Thermotrol electric casting method. This almost certainly results from the relationship existing between the casting ring and the electric crucible of the Thermotrol which retains more heat, allowing slower cooling and hence the formation of larger grains in the casting.

It is generally accepted that a smaller grain size gives better physical properties in terms of higher ultimate tensile strength and lower ductility. It has been observed that for casting gold alloys, although the grain size of Thermotrol castings may be twice that of gas-air castings, there is no significant difference in hardness and hence ultimate

tensile strength between these types of castings. Other factors than grain size may be of importance with regard to cast gold structures. Porosity control may be one of these. Hardness and strength as well as ductility, are governed by order-disorder reactions producing space lattice straining, which occurs within the grains.

Surprisingly, castings produced using Jelenko Firmilay and Modulay did not exhibit a smaller grain size than the Precious Metals alloys. Claims have been made by Jelenko (Shell, 1964) that Jelenko alloys are "microfined" exhibiting grain sizes of approximately 50 microns. This has not been borne out in this study. Jelenko alloys sold on the open market in Australia, are made in Australia for Jelenko, and perhaps have not been subjected to the microfining process used by the Jelenko Company in the United States. It is possible that this microfining has an insignificant effect on the properties of the gold alloys, even where it does occur. It has been found for annealed 70 - 30 brass that, not until the grain diameter falls below approximately 40 microns, do significant changes occur in ductility and tensile strength (Van Vlack, 1960). Similar grain sizes may be necessary in casting gold alloys to produce significant changes in physical properties.

A study of grain sizes of types A, B and C golds

leads to the conclusion that A golds have the largest grain size, B golds have a grain size between that of A golds and C golds.

A study of the structure of soldered joints, soldered using gas-air at a temperature of approximately 750°C and soldered in an electric furnace at 850°C throws considerable light on a number of aspects of dental soldering procedures.

The gas-air soldered joints when studied at a magnification of 50X appeared to exhibit a lack of alloying, as evidenced by a dark space occurring between the castings and the solder, as well as differing grain sizes in the solder and parent metal and lack of continuity of grain boundaries across the interface. These features are very well demonstrated in figures 7(a), 8, 11, 26(a).

Electrically soldered joints, soldered at 850°C , studied at a magnification of 50X appeared to exhibit complete alloying between the parent alloy and gold solder, with no dark interface area, the same grain size in parent alloys and solder, and continuity of grain boundaries across the junction between the casting and the solder. Despite evidence of excellent alloying, the solder could be clearly distinguished from the parent alloys. Examples of electrically soldered joints exhibiting the above features are seen in figures 7(b), 15, 25.

Electric soldering has been observed to cause more grain growth than gas-air soldering, although there is grain growth in gas-air soldering, no doubt due to the longer time involved in this process and the slower cooling after soldering takes place.

The above observations tend to confirm the work of Ryge (1958) and El Ebrashi et al (1968). These workers claim that soldered joints, where heating to a higher temperature has been employed, exhibit inferior properties to those where lower temperatures have been employed and alloying has not taken place. Neither worker presents data in support of this claim. If no marked diffusion or alloying takes place it is difficult to envisage the mechanism of the bond. It might be considered similar to the "interdenticle" bond where zinc phosphate dental cement is used.

Study of the two types of soldered joints after bending demonstrated that in both types of soldering slip planes occur in the solder as well as the parent alloys and these were seen to cross the interface area in the gas-air soldered joint as well as in the higher temperature, electrically soldered joint. This could not occur if diffusion and alloying had not taken place. Slip planes within individual grains are parallel within a single grain and are in different directions in different grains. When studied at a magnification of 1000X the nature of the

apparent interface can be seen very clearly. What appears to be a dark space at low magnification is, in fact, simply an extension of the dendritic structure in the parent alloy. This is particularly evident in figure 27(b). The dendritic appearance particularly where the darker accentuation occurs results, not from contamination and oxidation, but from a composition differential occurring because of lack of time for equilibrium to be reached. Alloying has taken place at the surface of the parent alloy rather than primarily along grain boundaries. This is not unexpected considering the higher energy at the surface than along the grain boundaries.

Alloying takes place without the actual melting of the parent alloys.

From table VII it can be seen that no significant difference exists between the strength of gas-air soldered joints and electrically soldered joints. Although at first consideration a difference does exist, using the "t" test it was determined that this difference is significant only at the 90 per cent level of confidence. Differences of this order are even less significant clinically. Typical soldered joints in fixed bridges have a cross-sectional area of approximately one-fiftieth of a square inch. The tensile load necessary to fracture such joints lie in the range of 800 pounds to 1000 pounds.

Porosity in the parent alloys may have an influence on the porosity of the soldered joint. This was shown in figures 4 and 7(b), and more particularly in figure 15. Here the region of the soldered joint adjoining a relatively porous area of one casting is extremely porous, while the porosity in the area of solder adjacent to the less porous casting is almost free of voids. An improvement, in soldered joints, may be produced by de-gassing the parent alloys before soldering, although any improvement is not likely to be clinically significant.

Observations regarding soldering without the aid of flux indicate that this can be achieved with some degree of difficulty. Although generally the resultant soldered joints are structurally sound and frequently void free, the risk of melting the original castings is considerable. Care should be exercised in using flux to attempt to minimize spherical flux voids which are frequently observed in sectioned soldered joints. These are demonstrated in figures 4, 8, 12, 15.

The problem of air entrapment has been pointed out, and this may occur, particularly where solder is drawn into the joint from two sides, particularly where sufficient gap is not present. Usually a gap of .004" - .006" should be used for most

consistent results. Smaller gaps may produce incomplete solder joints, while larger gaps provide poor aesthetics, a small spherical contact between solder and parent metal or problems in gauging the amount of solder required to adequately join the parent castings.

Surfaces of gold castings to be soldered should be clean, but no advantage is gained by producing a high polish on the castings. On the other hand, since the soldered joint does not require a mechanical bond, no advantage is gained by leaving a roughened surface. By not completely polishing the casting before soldering, problems may be encountered in the final polishing of a casting after soldering because of poor access. To ensure cleanness, if complete polishing is not carried out, grinding to the stage of a fine sandpaper or cuttlefish disk should be completed.

A study of table VI indicates that Precious Metal C type gold and 18K gold were affected significantly by both softening and hardening heat treatments. Precious Metal A and B golds and Jelenko Firmilay and Modulay were not found to respond to heat treatments.

The hardness values of 18K gold solder parallel those for Precious Metal C gold for the same heat treatments. It

may be deduced that the ultimate tensile strengths of gold solder and C gold would likewise be similar. This is supported by the data presented in table VII where the tensile strengths of Precious Metal C gold alloy, as cast, is not significantly different from that of a tensile specimen in the as soldered condition, either soldered using gas-air or soldered electrically.

Heat treatments had no effect on the grain structure of casting gold alloys or gold solder. Changes in physical properties occur because of order-disorder reactions producing lattice straining by movement of gold and copper atoms. The temperatures employed in heat treatments are not sufficient to produce grain growth.

Contact point soldering, using a Bunsen burner, to momentarily melt the solder, thereby ensuring minimal heating, produces a structure similar to that observed in gas-air soldering. At low magnification there is apparent lack of alloying. Study at 1000X reveals that alloying and diffusion have taken place, and the apparent dark space at the interface in figure 20 is an accentuation of the dendritic structure previously discussed. The hardness value of 18K gold solder is considerably higher than the hardness of type A and type B golds, although not significantly higher than the hardness of type C gold. There would seem to be little purpose in

soldering a contact on a type C gold casting unless an actual deficiency occurs, but a harder and probably better wearing contact could be produced with solder where type A or type B golds were being used.

A relationship has been established between Hardness (V.H.N.) and Ultimate Tensile Strength. Hardness values have been determined using a 100 gm. load. This load has the advantage of producing a small indentation, which may be placed on casting gold alloy, or gold solder so that valid results may be obtained. The hardness tested represents the hardness of the gold alloy or solder itself and does not represent an overall value dependent on the inclusion of voids under the indenter. Since factors occur at the space lattice level, which affect the physical properties, a 100 gm. load has many advantages over hardness values obtained using a higher load. Although a straight line relationship exists between hardness (V.H.N. 100 gm.) and ultimate tensile strength, this relationship is different for gold solder and casting gold alloy. As mentioned previously, the hardness of the gold solder appears to have been increased more as a result of the tensile test than the hardness of the casting gold alloy and, in actual fact, the relationship line for gold solder probably lies approximately parallel to the two lines in figure 21, and between them. There is a need for the

establishment on a statistical basis of a comparison between hardness, before and after testing, and ultimate tensile strength. Skinner and Phillips (1967) quote a ratio of Ultimate tensile strength : Brinell Hardness approximately 500 : 1 for casting gold alloys.

This ratio has not been substantiated in this study for V.H.N.

Problems would arise in the use of Brinell Hardness with a load of 15 kg. particularly with gold solder. This load would produce indentations approximately 300 microns in diameter, which is wider than most soldered joints.

In attempting to establish a relationship between ultimate tensile strength and hardness (V.H.N.) for soldered joints, it appears that it is the hardness of the solder which would give a guide to the strength of the joint being tested, rather than the hardness of the associated parent alloys. This is supported by the fracture paths generally observed in tensile specimens, as seen in figure 22.

The stress strain curves studied in this investigation have tended to indicate that although the ultimate tensile strength values compare with those claimed by the manufacturer, proportional limits and elongation are higher than claimed by the manufacturer.

SUMMARY.

1. A study has been made of the structure and some physical properties of casting gold alloys and gold solder.
2. Porosity in gold castings has been studied in relation to its effect on the structure of the soldered joint.
3. The effects of casting methods and heat treatments on casting gold alloys have been outlined.
4. The effects of soldering variables on the physical properties and microstructure of casting gold alloys and soldered joints have been studied, and some pertinent findings reported.
5. Contact point soldering has been carried out and the nature of the joint achieved has been observed.
6. Relationships between ultimate tensile strength and hardness (V.H.N.) have been established, and the need for further work in this field outlined.
7. A detailed metallographic study of joints, (i) soldered using a Bunsen burner, (ii) a gas-air blow torch for a minimum time at a temperature of 750°C , or (iii) where soldering is carried out at a temperature of 850°C in an electric furnace, has been carried out. All of these techniques produce alloying and diffusion at the solder-casting interface.
8. Soldering at higher temperature, below the melting point of the parent alloys, does not produce significantly weaker soldered joints than those produced at lower temperatures.

I.

BIBLIOGRAPHY

- AMERICAN SOCIETY FOR METALS : Metals Handbook, 1948 Ed.,
Cleveland, U.S.A.
- ANDERSON, J.N. : Applied Dental Materials, Ed. 3, Oxford and
Edinburgh, 1967, Blackwell Scientific Publications.
- ANDERSON, T.R., FAIRHURST, C.W. AND RYGE, G. : Method for
Evaluation of Dimensional Changes in Dental Bridge
Soldering. J.D. Res., 37:96, 1958 (Abstract).
- ANTE, I. : Soldering and Its Difficulties. Brit. D.J. 39:
380-387, 1918.
- ASGAR, K. AND PEYTON, F.A. : Pits on the Inner Surface of
Cast Gold Crowns. J. Pros. Den. 9:448-456, June 1959.
- BAILEY, P.B.E. : Gold Inlay -- A review of the methods and
materials used in obtaining gold castings for intra or
extra coronal fixation with reference to the handling
of those materials for optimal clinical result.
University of Sydney, M.D.S. thesis, 1962.
- BRUCE, R.W. : Evaluation of multiple unit castings for fixed
partial dentures. J. Pros. Den., 14:939-943, Sept.-Oct.
1964.
- BRUMFIELD, R.C. : How to vent full cast crown moulds to avoid
gas porosity. The Thermotrol Technician, March 1950.

II.

- BRUNO, S.A. : A one-piece fixed bridge. J. Pros. Den.,
5:401-407, May 1955.
- COLEMAN, R.L. : Physical properties of dental materials.
National Bureau of Standards Research paper No. 32,
Washington, U.S. Government Printing Office, 1928.
- COLEMAN, R.L. : Physical properties of dental materials
(cast gold alloys). D. Cosmos, 69:1007, Oct., 1947.
- CRAWFORD, W.H. : Selection and use of instruments, sprues,
casting equipment and gold alloys in making small
castings. J.A.D.A., 27:1459-1470, Sept. 1940.
- CROWELL, W.S. : Dental Gold Solders. Metals Handbook,
American Society for Metals, 1948 Ed., Cleveland, U.S.A.
- DYKEMA, R.W. : A study of the effects of certain variables
on the comparable strengths of soldered and cast bridge
joints. Master's thesis, Indiana University School
Den., June 1961. (Quoted in the Modern Practice in
Crown and Bridge Prosthodontics, by Johnson, Phillips
and Dykema).
- EL-EBRASHI, M.K., ASGAR, K. AND BIGELOW, W.C. : Electron
Microscopy of Gold Soldered Joints. J.D. Res., 47:
5-11, Jan.-Feb. 1968.

III.

FUSAYAMA, T. : Factors and Technique of Precision Casting.

Part I, J. Pros. Den. 9:468-485, May-June 1959.

FUSAYAMA, T. : Factors and Technique of Precision Casting.

Part II, J. Pros. Den. 9:486-497, May-June 1959.

FUSAYAMA, T. : Technical Procedure of Precision Casting.

J. Pros. Den., 9:1037-1048, Nov.-Dec. 1959.

FUSAYAMA, T., WAKUMOTO, S. AND HOSODA, H. : Accuracy of Fixed

Partial Dentures made by various soldering techniques and

one-piece casting. J. Pros. Den., 14:334-342, March-

April 1964.

GABEL, A.B. : The American Textbook of Operative Dentistry.

Ed. 9, Philadelphia, 1961, Lea & Febiger.

GUY, A.G. : Elements of Physical Metallurgy. Ed. 2, Reading,

Mass., 1960, Addison-Wesley Publishing Co.

HOLLENBACK, G.M., SMITH, D.D. AND SHELL, J.S. : The Accuracy

of Dental Appliances Assembled by Soldering. Part II.,

Calif. Dental Ass., 42:1-5, April 1966.

JELENKO, J.F. : Crown and Bridge Construction. A Handbook

of Dental Laboratory Procedure. Ed. 5, 1964, J.F.

Jelenko & Co., Inc., New Rochelle, New York.

KENL, G.L. : The Principles of Metallographic Laboratory

Practice. 3rd Ed., New York, 1949, McGraw Hill Book Co.

IV.

- KEY, D.A. : A study in Casting Density. J.A.D.A., 32:25-30,
Jan., 1945.
- KOVALESKI, T. : A study of Soldering Distortion on Fixed and
Removable Partial Dentures. The Thermotrol Technician,
Vol. 12, No. 1, Jan.-Feb., 1958.
- LANE, J.R. : A Survey of Dental Alloys. J.A.D.A., 39:421-437,
Oct. 1949.
- LEFF, A. : An Improved Temporary Acrylic Fixed Bridge. J.
Pros. Den., 3:245-249, March 1953.
- LEINFELDER, K.F., FAIRHURST, C.W. AND RYGE, G. : Porosities
in dental gold castings, II. The effects of mold
temperature, sprue size and dimension of wax pattern.
J.A.D.A., 67:816-821, Dec. 1963.
- MYER, F.S. : The Elimination of Distortion During Soldering.
J. Pros. Den., 9:441-447, May-June 1959.
- O'BRIEN, W.J. : A Digest of Current Casting Research. The
Thermotrol Technician. Vol. 14, No. 4, Jan.-Feb. 1960.
- O'BRIEN, W.J. : Soldering Tips from the Research Department.
The Thermotrol Technician. Vol. 14, No. 4, Sept.-Oct.
1960.
- O'BRIEN, W.J., HIRTHE, W.M. AND RYGE, G. : Wetting Character-
istics of Dental Gold Solders. J.D. Res., 42:675-680,
March-April 1963.

V.

- PENZER, V. : Fixed Bridges Without Soldering. J. Pros. Den., 3:718-720, Sept. 1953.
- PERDIGON, G.J. AND VAN EEPPEL, E.F. : Minimizing Solder Joint Warpage in Fixed Partial Denture Construction. J. Pros. Den., 7:244-249, March 1957.
- PEYTON, F.A. : Flexure Fatigue Studies of Cast Dental Gold Alloys. J.A.D.A., 21:394-415, March 1934.
- PEYTON, F.A. et al : Restorative Dental Materials. Ed. 2, St. Louis, 1964, The C.V. Mosby Co.
- PHILLIPS, R.W. : Studies on the Density of Castings as related to their Position in the Ring. J.A.D.A., 35:329-342, Sept. 1947.
- RUBIN, J.G. AND SABELLA, A.A. : One Piece Castings for Fixed Bridgework. J. Pros. Den., 5:843-847, Nov. 1955.
- RYGE, G. : Dental Soldering Procedures. Dental Clinics of North America. Philadelphia, Nov. 1958, W.B. Saunders Co.
- RYGE, G., KOZAK, S.F. AND FAIRHURST, C.W. : Porosities in Dental Gold Castings. J.A.D.A., 54:746-754, June 1957.
- SAMUELS, L.E. : The Use of Diamond Abrasives for a Universal System of Metallographic Polishing. J. Inst. Metals. 81:471-478, 1952-53.
- SAMUELS, L.E. : Metallographic Polishing by Mechanical Methods. Melbourne and London, Pitman & Sons, 1st Ed. 1967.

VI.

- SAUSEN, R.E. AND SERR, H.H. : Diameter of Sprue Former for Various Uses. Dental Clinics of North America, Philadelphia, Nov. 1958, W.B. Saunders Co.
- SHELL, J.S. : Gold Casting -- With Reference to Cast Gold Inlays. J.A.D.A., 10:187-200, March 1923.
- SHELL, J.S. : Casting Gold Alloys: Their Physical Properties and Dental Application. J.A.D.A., 18:904-916, May 1931.
- SHELL, J.S. : Today's Dental Soldering. The Thermotrol Technician. Vol. 16, No. 3, May-June 1962.
- SHELL, J.S. : Microfine Grain Structure in Cast Gold Alloys. The Thermotrol Technician. 18:1-4, Mar.-Apr. 1964.
- SKINNER, E.W. : The Science of Dental Materials. Ed. 4, Philadelphia, 1954, W.B. Saunders Co.
- SKINNER, E.W. AND PHILLIPS, R.W. : The Science of Dental Materials. Ed. 6, Philadelphia, 1967, W.B. Saunders Co.
- SOUDER, W. AND PAFFENBARGER, G.C. : Physical Properties of Dental Materials, National Bureau of Standards Circular C 4 33, Washington, U.S. Government Printing Office, 1942.
- SPIEGEL, M.R. : Theory and Problems of Statistics. New York, Schaum Publishing Co. October 1961.
- SPRENG, M. : Metallkunde fuer den Zahnarzt. Basel, Schweiz. Appollonia-Verlag., 1940. (Quoted in The Science of Dental Materials, Ed. 6, by Skinner, E.W. and Phillips, R.W.)
- STEINMAN, R.R. : Warpage produced by Soldering with Dental Solders and Gold Alloys. J. Pros. Den., 4:384-395, May 1954.

VII.

- STRICKLAND, W.D. AND STURDEVANT, R.E. : Porosity in Full Cast
Crowns. J.A.D.A. 58:69-78, April 1959.
- SUFFERT, I.W. AND MAHLER, D.B. : Reproducibility of Gold
Castings made by present day dental casting techniques.
J.A.D.A. 50:1-6, Jan. 1955.
- TAMARIN, A.H. : Fixed Bridge with One Piece Cast Backing.
J.A.D.A. 62:490-491, April 1961.
- TAYLOR, N.O. AND TEAMER, C.K. : Gold Solders for Dental Use.
J.D. Res., 28:219-227, June 1949.
- THOMPSON, E.C. : The Manipulation of Wax, Investments and
Casting Gold. J.A.D.A. 11:203-220, March 1924.
- TYLMAN, S.D. : Theory and Practice of Crown and Bridge
Prosthesis. Ed. 4, St. Louis, 1954, The C.V. Mosby Co.
- VAN VLACK, L. : Elements of Materials Science. 1st Ed.,
Reading, Mass., 1959. Addison Wesley Publishing Co.
- WETTERSTROM, E.T. : The Importance of Soldering Operation.
The Thermotrol Technician, Vol. 22, No. 1, Jan.-Feb. 1968.
- WETTERSTROM, E.T. : Factors Influencing Soldering Technics.
The Thermotrol Technician, Vol. 22, No. 2, Mar.-Apr. 1968.
- WILKINSON, J.V. : The effect of high temperatures on stainless
steel orthodontic arch wire. Aust. D.J., 5:264-268,
Oct. 1960.

