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## The Experiment on Melted Mark Formed by Copper Wire in Electrical Fire and the Analytic Researcher on the Feature Parameters of Metallographic Structure

WEI Mei-mei<sup>a,b,c</sup>, MO Shan-jun<sup>a,b</sup>, LIANG Dong<sup>a,b,\*</sup>, LI Ji-bo<sup>a,b</sup>

<sup>a</sup>*Safety Engineering Research Center, Department of Engineering, Sun Yat-sen University, Guangzhou 510006, China*

<sup>b</sup>*Guangdong Provincial Key Laboratory of Fire Science and Technology, Guangzhou 510006, China*

<sup>c</sup>*Wuhan Energy Saving Monitoring Center, Wu han, Hubei 430014, China*

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### Abstract

This essay based on a series experiments simulated the real electrical fire situation to get the metallographic structure pictures of heated copper wire. The results of the experiment are proved by the real cases. A digital image processing software is adopted to quantitative the demotion of the metal crystals. The findings is that the average diameter of metal crystals changes with temperature varied. The relation between the diameter and the environment temperature can describe with a curve. The high the temperature the diameter of the crystal is bigger. The diameter is also determine by melted mark cooling method.

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Keywords: electric fire; copper conducting wire; burned melted mark; Digital image; metallography analysis

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### 1. Introduction

The melted copper conducting wire and melted deans, the remainder after a fire, are an important material evidences. Through identifying what the melted mark type is, we can find out the reasons for the fires.

The cross-section area of copper cable in low voltage buildings is less than 2.5mm<sup>2</sup>. The pure degree of copper is 99.95%, the density 8.9g/cm<sup>3</sup> and the melting point 1083°C. The initial type of metal crystal in the copper cable is the face centered cubic and then transformed into equiax crystal after anneal. In common sense, the type of crystal in copper cable is small size equiax crystal. When the copper conducting was stretched the euuix crystal become fibrous structure. The metallographic structure of new cable is annealed structure. When normal power circles in the wire, the metallographic structure should be in certain direction. If the temperature reached the range of 200 to 280 °C and was kept for a while, the direction of the metallographic structure fade away subsequently. When the

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\* \* Corresponding author. Tel.: +86-20-3933-2230; fax: +86-20-3933-2927.

E-mail address: [gzliangd@163.com](mailto:gzliangd@163.com)

temperature is as high as 600°C, the recrystallization of metallographic structure happens. The higher the temperature is, the bigger the gains in the copper cable will become.

Through deservng the metallographic structure we can speculate the process of heating. The time that metal in high temperature has great influences on the size of the metal crystal.

In addition, the water jetting, which has high degree undercooling, used to put down the fire also has impact on the metallographic structure of the cable. By deservng the metallographic structure change rule of the metal cable in the fire place and the metal evidence in the fire spot, we could know the temperature, combustion time, details of cooling and so on.

In this paper the laws of metallographic structure change is discussed to divide the type of the short circuit melted mark. A series of equipments are used to research and identify the metallographic structure deeply in order to estate a database about the metallographic image. A quantitative analysis method is used to process the metallographic image to get the relation between the feature parameters of metallographic structure and the environment of fire place.

## 2. Experiment

### 2.1. *equipment, material and facilities of analysis*

(1) experiment equipments: Bunsen burner, muff furnace, temperature sensor and YMP-2 metallographic sample muller (sand paper 2000#, 800#), PG-2 polisher (rotate speed 1400r/min, 900r/min), beaker, plastic container, muddler, electric hair-drye.

(2) experiment material: single-core copper cable with 2.5mm<sup>2</sup> cross-section area and insulating layers of PVC, FeCl<sub>3</sub> solution, absolute alcohol, denture base resin (type II), deerskin, diamond powder and coal oil.

(3) facilities of analysis: electronic balance, Leica DMI metallurgical microscope, data collector

### 2.2. *experiment aims*

In this experiment metallurgical microscope and pictures processing software are used to get the map, the curve and the datasheet between the metallurgical structure of copper cable and the temperatures. The direct and quantitative identification criterions of melted mark and melted beans are established. All these maps and criterions are very useful in fixing on the direction of fire extending, as well as identifying the fire spot and the cause for real fire cases.

### 2.3. *the making of fire melted mark sample*

(1) making the fire melted mark sample

A fire melted mark is formed by fire. In commonly there is no current in the wire at the moment. There are two methods to get the sample by experiment. One method is to heat the copper wire by a bunsen burner with 1200°C. The other way is to put the wire in a muff furnace and then heat it.

In this experiment most samples are heated in the muff furnace. Copper wire samples are put into the muff furnace and then the environment is changed with the temperature rising. The followings are four different ways to produce samples.

(1) maximum temperature 1100°C, the time of heat preservation is 10 minutes.

(2) maximum temperature 1000°C, the time of heat preservation are 5 minutes, 10 minutes, 30 minutes respectively.

(3) maximum temperature 1000°C, the time of heat preservation 10 minutes, the following cooling has three different cooling ways, cooling in the muff furnace, natural cooling in the air, water-cooling.

(4) the samples formed in real fire case.

When samples of melted marks and melted beans are produced in the above ways, the next steps are making corresponding metallographic samples. First step is to clean the melted marks and melted beans using ethanol in. The following step is put the samples in a copper cube with diameter 2.5cm, and then pure the denture base resins into the copper cube. The third step is to smooth as well as to polish the samples. The last step is to process the

sample in  $\text{FeCl}_3$  solution and then to observe and analyse the shape, color, gloss, size, air hole as well as stripes of the microstructure with optical microscopy.

Table1-1 The different conditions of copper wire heat treatment

number	temperature(℃)	time(min)	Cooling type
1	200	10	Air-cooling
2	300	10	Air-cooling
3	400	10	Air-cooling
4	500	10	Air-cooling
5	600	10	Air-cooling
6	700	10	Air-cooling
7	800	10	Air-cooling
8	900	10	Air-cooling
9	1000	5	Air-cooling
10	1000	10	Air-cooling
11	1000	10	Water-cooling
12	1000	10	furnace cooling
13	1000	30	Air-cooling
14	1100	10	Air-cooling

3. the results and analysis of fire melted marks

3.1. the metallurgical atlas of fire melted marks

The samples of melted mark and melted beans with typical features are processed and the metallurgical images are took by the microscope. In order to research the metallurgical structure in quantitative methods, the dimension marks were drawn in the pictures with unit micron. The demonstrations to picture including heat time, time of heat preservation, type of cooling, magnifying time noted as X. The default way of cooling is air cooling if not indicated.

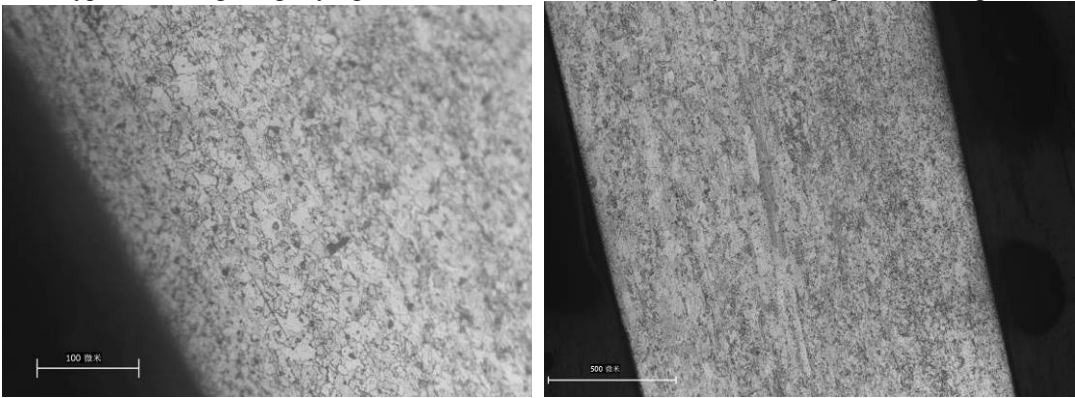


Fig.1.(a)original structure of copper wire200X;(b) 200℃-10min-50×

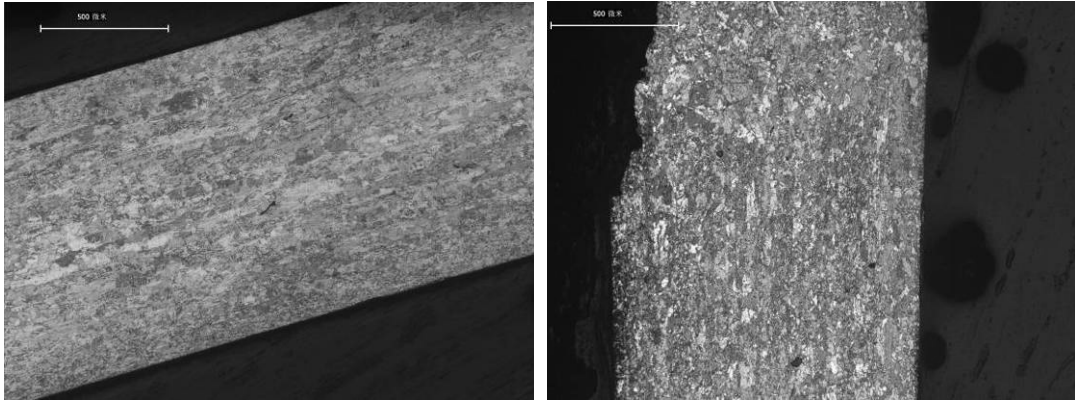


Fig.2.(a) 300°C-10min-50×;(b) 400°C-10min-50×

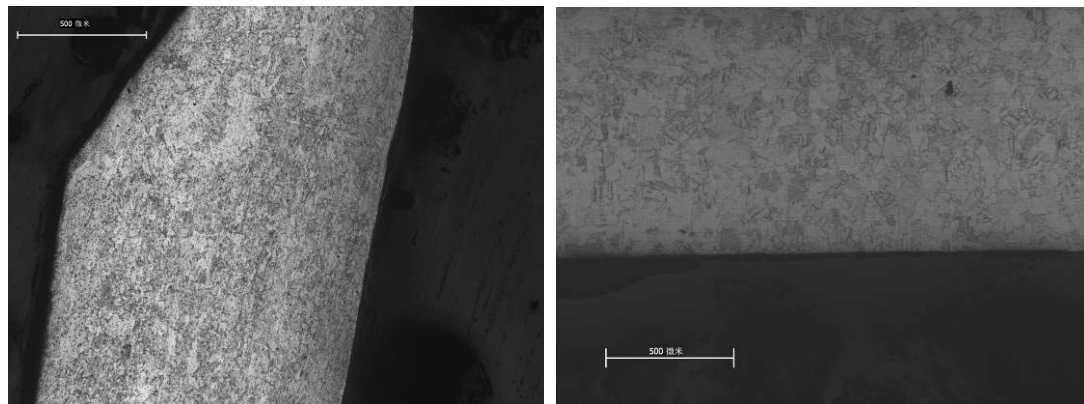


Fig.3.(a). 500°C-10min-50×; (b).600°C-10min-50×

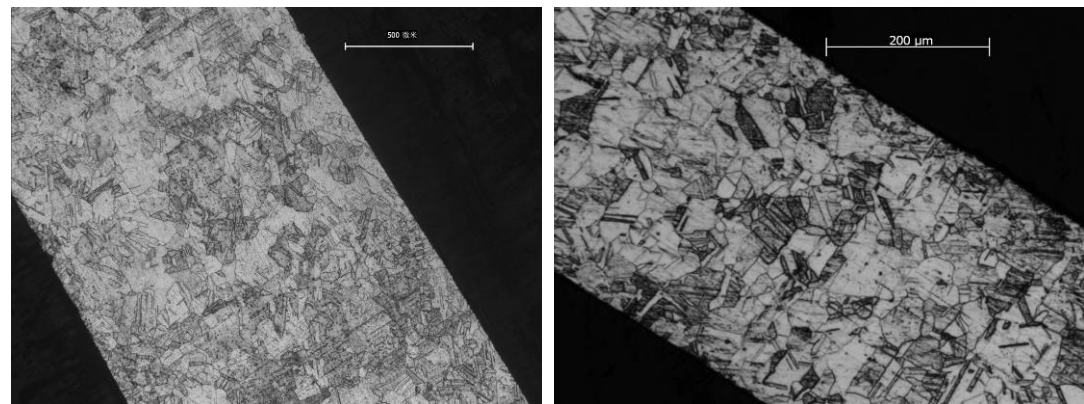


Fig.4.(a)700°C-10min-50×;(b) 800°C-10min-50×

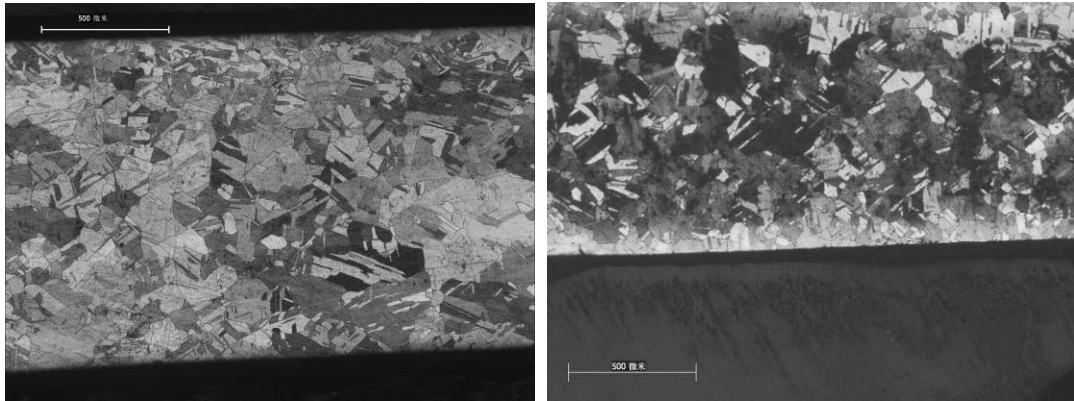


Fig.5.(a)900°C-10min-50×;(b) 1000°C-5min-50×

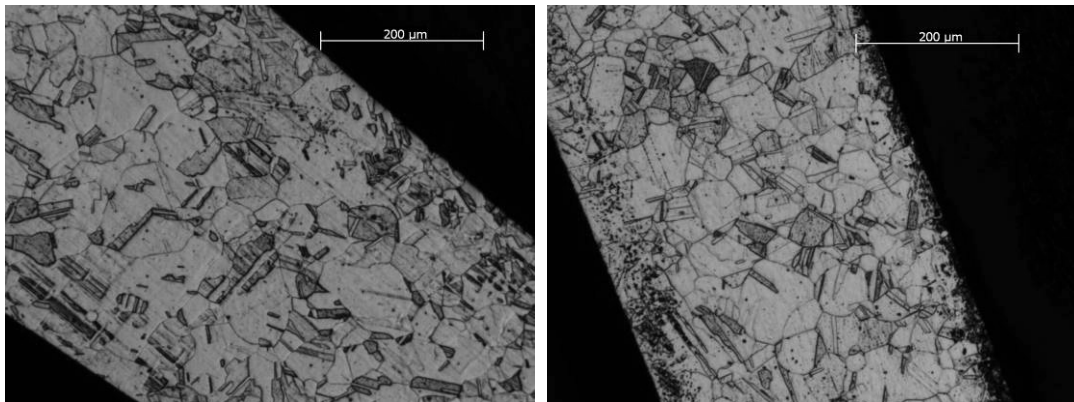


Fig.6.(a)1000°C-10min-50×;(b) 1000°C-10min-water cooling-50×

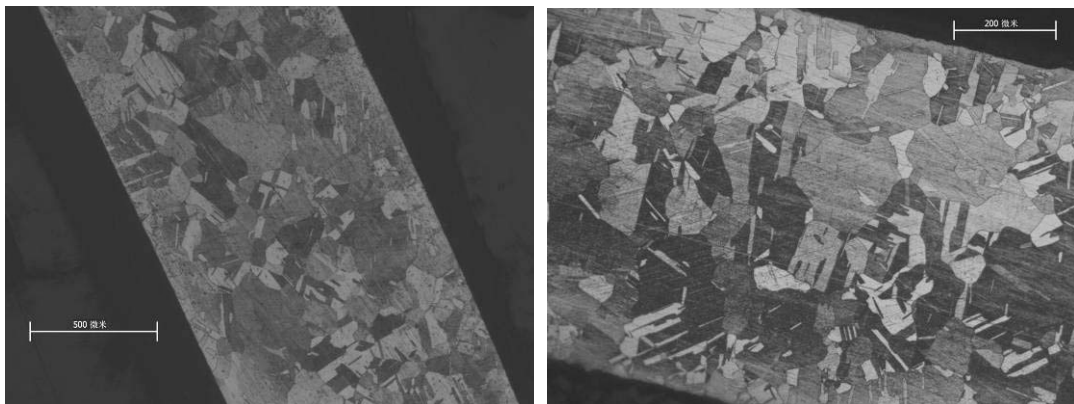


Fig.7.(a) 1000°C-10min-furnance-50×;(b) 1000°C-30min-50×

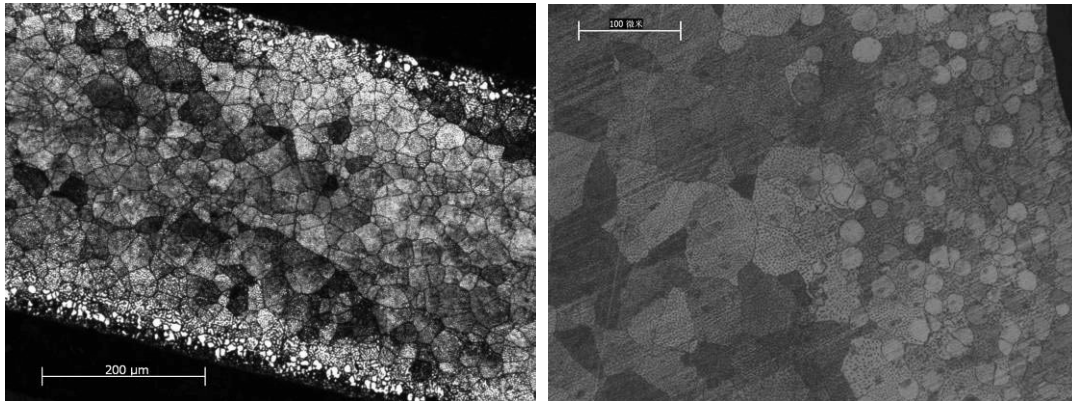


Fig.8. (a)1100°C-10min-50×;(b) 1100°C-10min-200×

### 3.2. The features of burned melted marks

Through studying the three groups of experiment samples by means of statistical analysis, we get the features and laws of the metallurgical structure obtained from the three groups as following.

(1) Fig.1.(a) shows the original microstructure of copper wire without anneal having visible direction. From fig 1(a) to fig.8.(b) we know that the diffusivity of metal atom in wires is insufficiency in temperature of room temperature to 220-280°C stress annealing temperature. And the metal atoms are relative stable in this range of temperature. Although some grains have a certain of recovery, the microstructure and the size of grain are largely unchanged. The direction of the microstructure is visible. When the temperature exceeds the recrystallization temperature of 500-600°C and rises

Continuously, the grains grow gradually along with the temperature rising. Some grains grew bigger and the other grains disappeared. The process of grain recovery and recrystallization took a length of time. Although the maximum temperature exceeds 1000°C, the 10minutes time of heat preservation in this experiment is short for grains growing. These fig.2.(b)and3.(a). showed that the recrystallization is not completed and the structure of grain is irregular and with directions. When the temperature reach 800-1000 °C, which is much more than the recrystallization temperature, the phenomena of recrystallization temperature happened in high temperature. The grains grew in short time and transformed into big equiaxed grains, showed from fig.3.(b) to fig.7.(b).

(2). Burned melted marks formed in fire with temperature higher than the melting point. The metallographic structure has the typical features of anneal organization. Because the process of heating and cooling happened respective slowly, the crystal core forms and grows during the transformation of melted mark from liquid to solid. The inner metallographic structure of the burned melted mark is big equiaxed grains.

When the temperature reached or exceeded the melting point, the microstructure of the wire changed obviously. If the temperature reach 1100°C, spots and grid patterns formed in places between the equiaxed grains and the initial equiaxed grains became blurry. The dispersion of Oxy

promote the shape of Cu and Cu<sub>2</sub>O crystal. Many small equiaxed grains and some column crystals formed on the edge.

(3) There is no transitional zone in the whole organization. The burned melted mark could absorb the oxygen in the air so that the oxidation reaction took place fully. Because the time of melted mark cooling and the solidification time of melted mark are long enough, the gas dispersed in the wire escaped completely. There is almost no gas holes in the metallographic structure with a glazed surface.

### 3.3. The sample metallographic structures of real fire case

A fire happened in a made clothing firm in zhongshan city , July thirty 2009. Fire investigators picked up segments of copper wires on the forth floor of the work place to analyze the microstructures.

The material evidence is two segments of single core copper wire, marked respectively as 1-1,1-2,with bolts at the end. A segment of relative thin wire is marked as Number 2 material evidence. The thinnest wire is noted as Num3 material evidence.

Metallography analysis show that the metallgrahpic structures of the melted mark were big equiaxed grains, and there were no air holes in the structures. This means it formed by fire(show in fig from 9.(a) to 10.(b)).The metallgrahpic structures of real case samples prove the design of the above experiment reasonable.

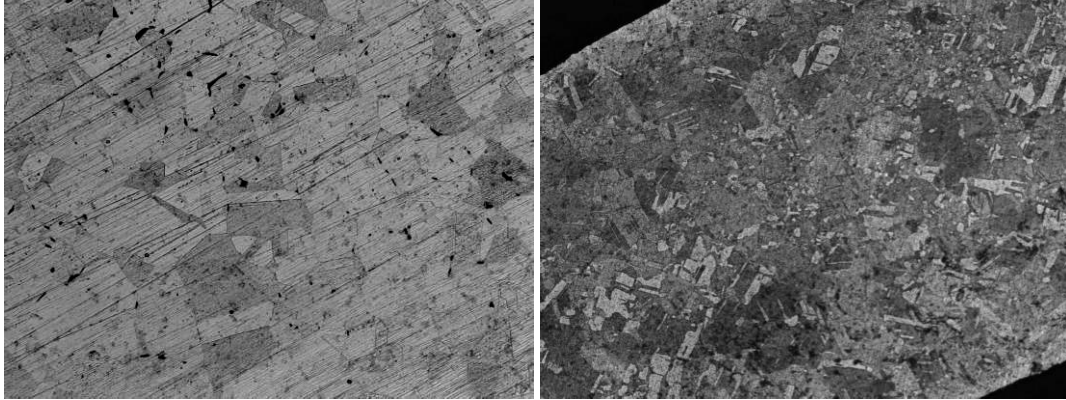


Fig.9. (a) the metallgrahpic structure of wire 200X;(b) the metallgrahpic structure of wire 100X

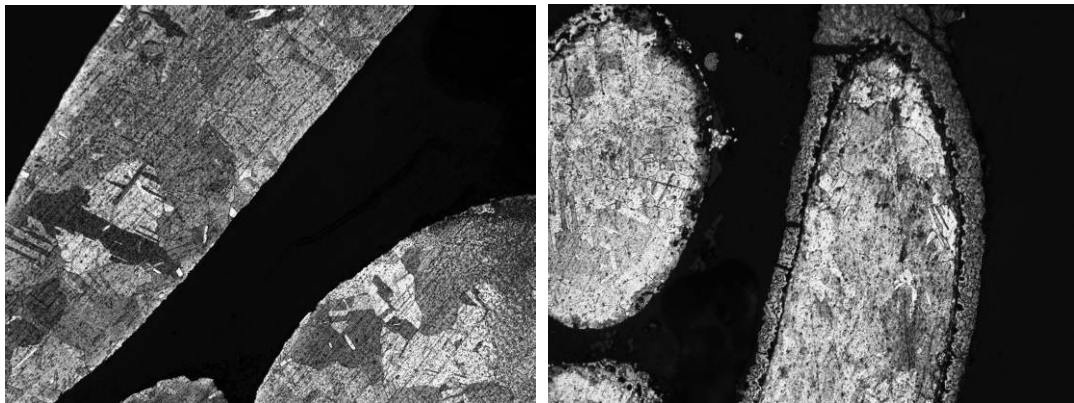


Fig.10.(a)the metallgrahpic structure of Num2 wire 100X;(b) the metallgrahpic structure of Num3 wire 200X

### 3.4. The influences of heating conditions to the metallographic structure characteristics

The metallographic image is a special microscopic image, which is based on material science and metallography and expressed by discrete data structure. The image taken by sensor is a continue function of two planar coordinates. The  $f(x,y)$  is a two-dimensional function,  $x,y$  representing respectively the coordinate values of  $x$  and  $y$  axis. The value of  $f(x,y)$  is define as the gray value of the point. The image is called digital image if the values of  $x$ ,  $y$  and  $f(x,y)$  are finite.

The process of digital images needs computers to completed combined with the theories ,methods and technologies of noise remove, quality enhancement, division as well as feature extraction. The advantages of the digital images include simple and fast measurement to parameters, small measure error, exact analysis results.

The workflow of quantitative measurement as following: image taking→dimension marks labeling→image pretreatment→division and identification of grain boundary→extraction of grain boundary feature parameters.

#### (1) The relations between the heating temperature and the size, rank of grains

The software is adopted to process the digital images ,identify and number the grains in the images as well as extract the grain boundary and feature parameter, shown in fig.11. It was found that if defined the temperature as a variable, the relation between grain dimension and temperature can be expressed as a curve in a certain range of temperature, shown in fig.12 and 13. When the temperature changes from room temperature to the recrystallization temperature, the size of grains is constant,6microns, within the grand 11.5 of size. The grain diameter grew gradually with the temperature rising from 200 degrees to 500 degrees in which the average diameter is in direct ration to temperature. When the temperature exceeds 600 degrees, the grain diameter grew rapidly from 12.5microns to 38microns, and the grain grand became from 9.9 to 6.5. This trend of the grain growth can be expressed in a curved. But if the temperature exceeds the melted point, the metal begins to melt on the surface and big light round  $\text{Cu}_2\text{O}$  particles with sings on the edge emerge. Meanwhile the average diameter of round particle is 19.4638micarons. Once the fire temperature is not very high, it is possible to speculate the heat temperature or the temperature range in partial region the sizes of the grain in the melted mark as well as get the basis to make sure where the fire point is.

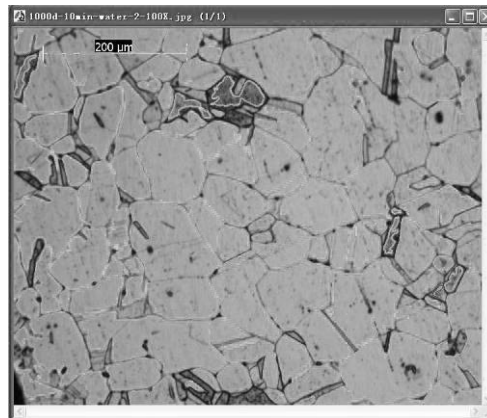


Fig.11. plotting out and distilling the borderline of crystal using the digital image processing



(2)The influence of cooling type and heat preservation time to the size of grain

Heat the copper wire to 1000 degrees and hold the temperature for 10min and then cool the wire in three different ways as water cooling, air cooling, furnace cooling. It was found that the type of cooling has little influence on the metal microstructure but the impact to the grain size is notable. Because the cooling process in muff furnace is longer, the average grain size is  $61.5\ \mu\text{m}$ , which is bigger than the size of grain formed in water cooling and air cooling. The metal crystal size has relation with the metal cooling types. During the metal transformation from liquid state to solid state, the larger the undercooling, the more there were crystal cores in the liquid metal. There were plenty of small grains with the crystal cores as center when the crystallization is completed. Hence, the size of grain formed in water cooling is smaller than the size in air cooling, respectively  $37\ \mu\text{m}$ ,  $40\ \mu\text{m}$ , showed in fig.14. The oxidation of the water cooling grain surface is lighter than that of air cooling grain.

The cooper conducting wire recovery and recrystallization as well as the grain growth need a length time to take place. If the heat treatment time is short, the inner atoms of copper wire are at the begin of diffusion and then the metal is cool. The recovery and recrystallization didn't completed and the change of metallographic structure is not big. So the heat and heat preservation time is a critical factor for the wire microstructure change. In common, take the heat time as a variable, the grain size is in direct ration to the heat time. So the grain grow as the time rising till reach a certain level and the growth speed slow down. The fig.12 below show the grain sizes from  $35\ \mu\text{m}$  to  $40\ \mu\text{m}$ , and to  $54.57\ \mu\text{m}$ , with heat preservation time 5mins, 10mins, 30mins respectively.

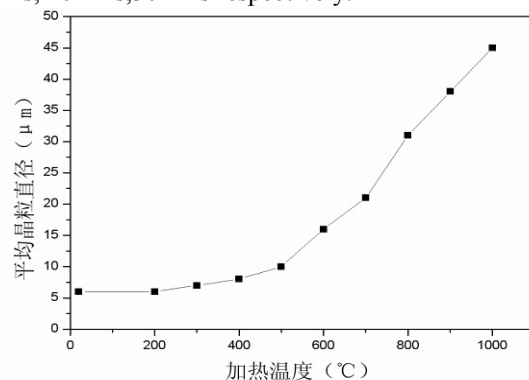
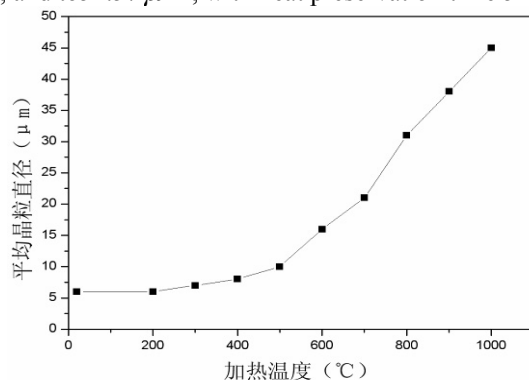


Fig.12.the relationship between crystal sizes and the temperature Fig.13.the relationship between crystal class and the temperature

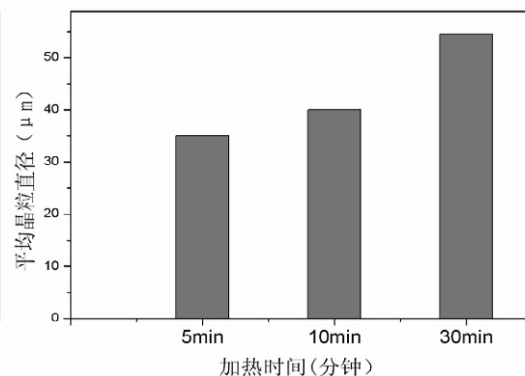
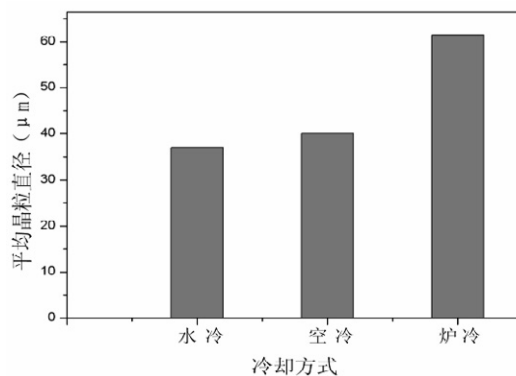


Fig.14.the relationship between crystal size and the cooling patterns Fig.15.the relationship between crystal size and the time of heat preservation

#### 4. Conclusion

By setting parameters such as the heat time, the temperature, cool speed and so on, the experiment was carried out and the influences of experiment process on the wire melted mark microstructure were got. The results are as follows.

1 The relation between grain size and the heat conditions. When the temperature is under the wire melt point the metallographic structure has the features of equiaxed grain and the grain boundary is big. The grain size grows with the heat temperature rising and the relation between the grain size and the heat temperature could express with a curve in a range of temperature. If the temperature is higher than the melt point, the grains are small round cell crystals and small column crystals.

2 The influences of cooling types on the grain size. The size difference of grains formed in water cooling and air cooling is small, compared with the bigger grain size in real fire places. The burned melted mark has neither air holes nor transition zone.

#### Acknowledgements

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