Research of Vehicle Electrical Fire Authentication Based on Metallographic Analysis

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Abstract. Vehicle electrical fires mostly are caused by the circuit fault, analyze the circuit molten marks by using the metallographic analysis to determine the circuit molten marks belongs to the primary or secondary molten marks is a important method for vehicle electrical fire authentication.

1. Introduction

Along with the rapid development of automobile industry, as well as the progress of electronic technology, the proportion of auto body electrical component was more and more large, more and more widely especially in high-grade car.To meet the requirements of higher comfort and intelligent, high-end automobile electronic control modules will be more and more developed, the degree of electrification on mid-range car also gradually increased.In general, the economy car need electronic control unit (ECU) for 10 to 12, the demand of ECU on large/high-end luxury car was as high as 70-120.Therefore, the higher the degree of electrification, the higher the risk of a fire at the electrical system.According to statistics, the electrical system failure was the main reason of vehicle fire, accounts for about 50%-60% of the total number[1].

2. The main types of the electrical system fire

The auto had lots of electrical wires, which were flammable and worked in high temperature, humidity, vibration, bump, impact and harsh environments.The vast majority of electrical system failure is the electrical wires failure.

2.1 Electrical wire short circuit

Usually, the vehicle wires insulation layer were made from PVC material, the material easily fall off after high temperature or long time to wear, which led to metal wires exposed and caused a short-circuit. In addition, the owner or maintenance personnel privately modified wire or installed electric equipment, or line insulation layer damaged, which was extremely easy to cause electrical short circuit.

2.2 Wires or electric devices poor contact

Vehicle wire poor contact mean the contact point of fire was not stable, resistance increased, caused the overheating, caused wire insulation layer or around inflammable ignition and caused a fire.The main causes of poor contact has any of the following points:

1) Wire plug in the vehicle electrical system after long time using effect electrochemical corrosion, caused the plug contact resistance largen;

2) If the installation of vehicle electrical wires and equipmenst did not reach the designated position or there is something wrong with the quality, easy to caused loose connection and the resistance value increased;

3) due to vibration, bump in the process of driving, easy to cause the connection-peg or line disconnect, connection-peg or line momentary on-off will produce induced current,generate electric spark, which the electric spark was high temperature, easy to ignite flammable material around.

2.3 The electrical wire overload

Vehicle electrical wiring was in accordance with the relevant standards and the load of electric equipment to choose the appropriate section configuration. If the user or the sales staff installed electrical equipment which the actual load of the wire was more than its rated load, the entire wire will be overheat.High temperature will ignite wire insulation layer and flammable material around, so will cause a fire.

2.4 Vehicle fire electrical equipment malfunction

Modern vehicle was becoming more and more electrical equipment ,which refer to the vehicle safety, comfortableness. When anything goes wrong with the electrical equipment in the working process ,it caused high temperature , ignited the plastic combustible around, caused vehicle fire.

3.Vehicle electrical fire authentication

3.1 Vehicle fire authentication process

Vehicle fire authentication need based on the information provided by the parties to investigate the fire ,that according to the principle of from light to heavy, outer to inner, analyzed the characteristic of damage part,the tendency of flame spread, determined the cause of vehicle fire, (figure 1).

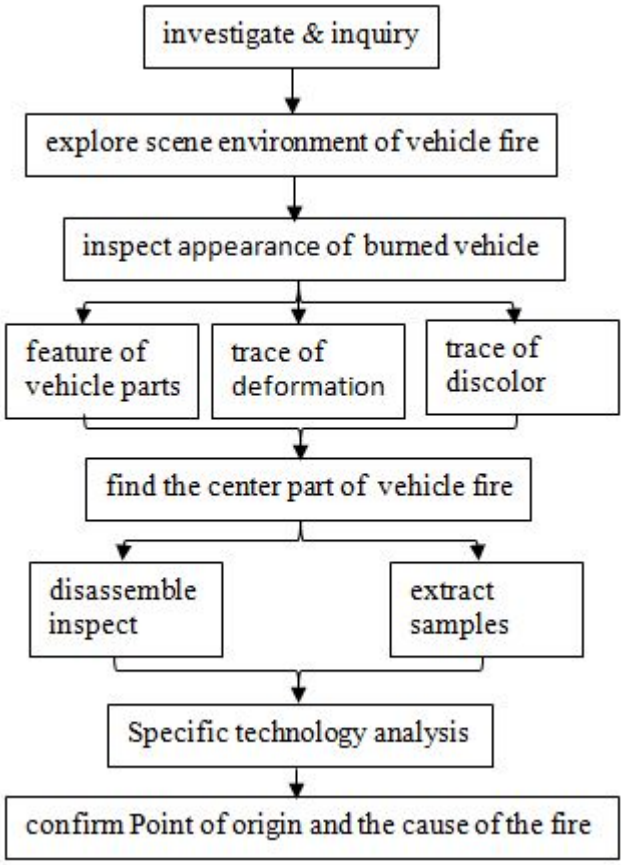


Figure 1 vehicle fire authentication process

3.2 Vehicle electrical fire authentication method

The authentication methods of vehicle electrical fire causes mainly include: the macroscopic method, the residual magnetism method, the composition analysis method, the metallographic method.At present, the macroscopic and metallographic method was the most widely used. The core of the principal phase method was by means of analyzing the appearance shape of metal wire melting scar and metallographic microscopic features to reflect the formation mechanism of metal wire melting scar.

Usually there are metal wire melting scar in vehicle fire scene. Via finding and extracting the metal wire melting scar of vehicle electrical wire and equipment, analyzing and researching the forming mechanism of metal wire melting scar ,observing its morphology and internal organizational structure of metal wire melting scar which formed in different environments, to ensure the metal wire melting scar was formed in fire or fire caused by wire short circuit, which is an important authentication method of vehicle fire.[3]

3.2.1 The basic principle of metallographic analysis

Metallographic analysis technology was summarized by our national famous fire investigation expert Mr Wang Xiqing , just had been applied in building fire. This formed a complete scientific theory of metallographic analysis technology after application and constantly improvement. The same metal present different organizational characteristics after different heat, heat preservation, cooling and a series of heat treatment, according to the characteristics of metal organization to analyze the different welding scar formation reasons.[1]

Metallographic analysis technology required technical personnel to have a basic understanding of the characteristics of metal organization, through comparing various organization characteristics under different environment and conditions, judging the formation mechanism of the characteristic of the metal organization,to correct find the cause of the vehicle fire.At the same time, technical personnel needed to accumulate a lot of practical experience to make the most accurate judgment, thus can find the correct cause of the vehicle fire.

3.2.2 Wires metallographic microscopic characteristics

3.2.2.1 Normal copper wires microscopic characteristics

Because the copper wire has good electrical conductivity, thermal conductivity and diamagnetism, so lots of copper wires is applied in vehicle electrical circuit.Copper wire is usually made up of 99.95% industry pure copper, density is 8.9 g/cm3, melting point is 1083 ℃, copper is face-centered cubic structure, so easy to become a equiaxed grain after the annealing, the microstructure of copper for a equiaxed grain (figure 2).In the process of drawing, copper wire is elongated in the direction of the deformation, has a certain direction, copper wire in the current state is still with the inerratic direction.When the temperature reach 200 ℃ to 280 ℃, the copper wire happens inside recrystallization phenomenon.After a certain time, copper wire's microstructure had changed.

3.2.2.2 Copper wire characteristic of burning melting scar

In vehicle fire,if the flame temperature was higher than the melting point of copper wire, the copper wire will form melting scar, this was burning melting scar.The metallographic microstructure of the burning melting scar presented coarse equiaxial crystal, smooth surface slicing, less holes (figure 3).This was related to the forming environment, which was high temperature. Copper wire temperature rised relatively slow in the environment,it is conducive to the formation of crystal nucleus, so the metallographic microstructure was coarse equiaxial crystal.At the same time, the cooling speed of wire was slow, lead to the solidification time was longer, this caused the burning melting scar in the process of solidification can happen redox reaction with the surrounding oxygen, fully absorbed the oxygen, formed copper oxide,nitrogen and other gases in chemical reactions, there are plenty of time to escape, to form a smooth surface.So metallographic specimen grinding surface was smooth and less holes .

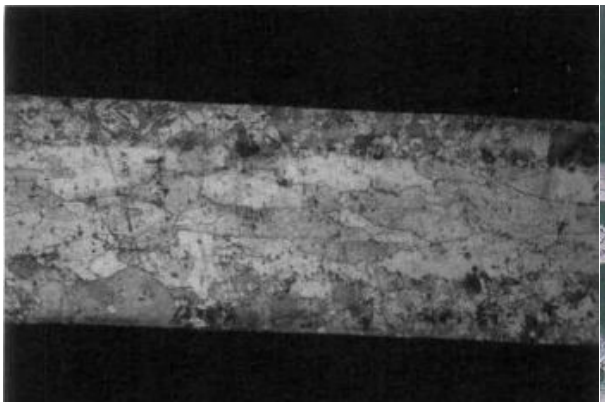
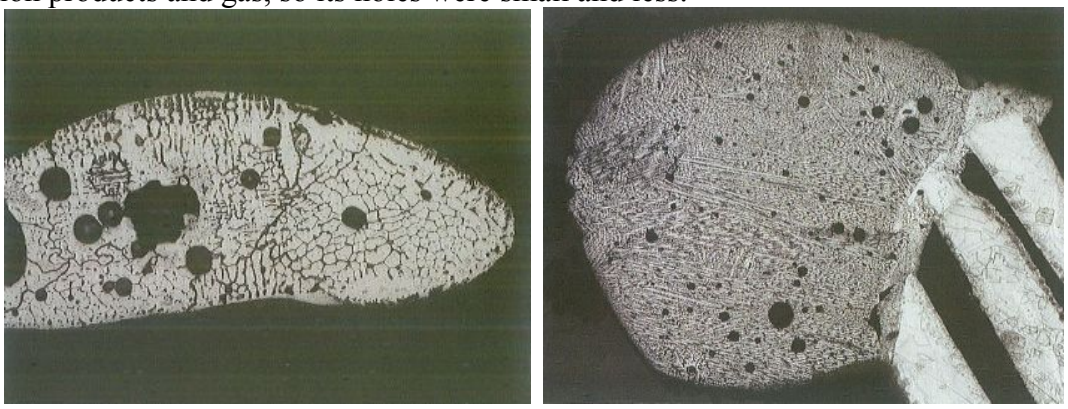


Figure 2 copper wire macrostructure

Figure 3 the burning melting scar metallographic microstructure of 100x

3.2.2.3 Copper wires characteristic of short circuit melting scar before fire

Copper wires short circuit melting scar was due to wires short-circuit itself lead to form metal melting scar, which formed before the fire, was the main cause of vehicle electrical fire. The short circuit melting scar before fire metallographic microstructure presented small columnar crystal or cellular crystal, eutecticum (Cu + Cu_2O) around the hole eutectic was less, the holes inside the organization was small and less and hole shape was circular or elliptic which relatively inerratic.There was obvious transition zone between melting scar and wire (figure 4).Due to short circuit occurred before fire, the melting scar formed fast. There was large temperture difference between wire and melting scar, the crystal had congealed before growing up, presented small closely packed cellular crystal or columnar crystal. The internal gas didn't had enough time to react and overflow, trapped within the organization, but melting scar in the process of formation had less combustion products and gas, so its holes were small and less.

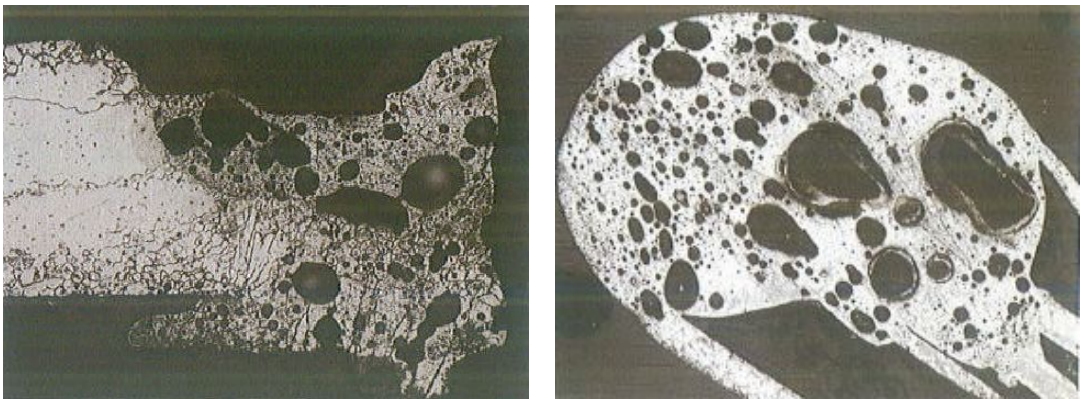


(a) (b)

Figure 4(a、b) short circuit melting scar before fire metallographic microstructure of 100x

3.2.2.4 Copper wires characteristic of Short circuit melting scar in fire

Copper wire of Short circuit melting scar in fire was wire insulation layer was burned by fire or melted by high temperature leads to the wire contact with the other wire to form short circuit,when the wire was under the condition of wire in the circuit conduction.Short circuit melting scar metallographic microstructure was composed of bulky columnar crystal or some big crystal boundary ,the internal holes were large and more, eutecticum (Cu + Cu_2O) around the hole were more apparent, transition zone between wire and melting scar was not obvious.Due to short circuit melting scar was formed in fire which the fire temperature is high, the melting scar cooled down slower and cannot effectively form the transition zone, if the scene of the fire temperature was constant high temperature, the transition zone boundaries will become more blurred and disorder;The cooling rate of short circuit melting scar was slow, more gas can not overflow, plus the air in fire contained more dust ,all kinds of combustion impurities,water vapor, therefore, these impurities will also enter the molten copper, so we can observe larger holes in this organization (figure 5).



（a） （b）

Figure 5(a、b) Short circuit melting scar in fire metallographic microstructure of 100x

3.2.3 The difference of short circuit melting scar before fire and Short circuit melting scar in fire

Short circuit melting scar and Short circuit melting scar in fire were high temperature melted by the instant short circuit arc, cooling rate was relatively fast, melting range was small.Their formation were different environment and conditions, so their metallographic microstructure were different.Short circuit melting scar before occurred in normal environment atmosphere, which was transitorily, low environmental temperature, fast cooling rate. Its metallographic microstructure was mainly presented columnar crystal ,which was fast cooling rate in low temperature.Short circuit melting scar in fire occurred in large area of the fire, the ambient temperature was high, cooling rate was slower, so short circuit melting scar crystal nucleus had plenty of time to grow, recrystallize,fuse and grow up, its microstructure was bulky columnar crystal or some big crystal boundary. Short circuit melting scar before fire and short circuit melting scar in fire had the following several different aspects:

(1) hole

The hole of short circuit melting scar before fire were small and little, inerratic, circular or elliptic. The hole of short circuit melting scar in fire were larger and more， anomalous， plus the air in fire contained more dust ,all kinds of combustion impurities,water vapor, therefore, these impurities will also enter the molten copper.

(2) eutecticum

Short circuit melting scar before fire formed under normal environment, fast cooling rate, short reaction time. Oxygen in the air didn’t had enough time to react with copper to generate Cu_2O, had overflow, so eutecticum ($Cu + Cu_2O$) was less around the hole. And short circuit melting scar in fire formed in the high temperature of fire, slow cooling rate. Oxygen had enough time to react with high temperature of molten copper, generated a lot of eutecticum ($Cu + Cu_2O$).

(3) the transition region

Copper wire was melted by the high temperature of short-circuit instantaneous arc to formed short circuit melting scar. due to short circuit melting scar occurred before the fire, the melting scar formed fast, the environmental temperature of wire and meltingscar were different, crystal didn't grow up before congealed. The short circuit melting scar before fire presented small closely packed cellular crystal or columnar crystal. Except the short circuit melting scar, the temperature of other area of wire is not high, the transition zone of metallographic microstructure presented the original state of isometric crystal elongated, which had certain direction, and the transition zone was obvious.Short circuit melting scar in fire formed under the environment of high temperature fire, effected by the high temperature, short circuit bead and crystal nucleus of transition zone have plenty of time to grow up to form bulky columnar or isometric crystal, if continued to heat under high temperature, the columnar crystal will grow into isometric crystal, the residual columnar crystal and transition area were not obvious.

4.Case application

Based on the comprehensive exploration at vehicle fire scene, combined with metallographic analysis of melting scar, and other materials, based on the analysis of many aspects,to appraisal results mutually is the commonly used method.Now only for the following actual case to metallographic analysis.

Figure 6 burned vehicle

Figure 7 burned engine compartment

A car drived into the community, after parking, suddenly engine compartment began to smoke.The front of the car body was damaged more seriously than the back of the body, showed a trend of obvious after former heavy light.Checked the car engine compartment, found that the front of the engine compartment was more serious than the back , the left side was more serious than the right side . The front of the car engine compartment damaged serious, aluminum alloy of front bumper right section ignited gonegone, front bumper left section had the smoke trace, preliminary analysis concluded was that the fire point of origin located in the front of the engine compartment, at the same time ， found a melting scar in the battery cathode copper wires, need to be further identified the melting scar was formed before the fire or in the fire, which is of great significance to find the real cause of the fire.Therefore, extracted the melting scar, no. 1(figure 8).

Made the sample to production of metallographic, observed its organizational characteristics by means of metallographic microscope (figure 9).

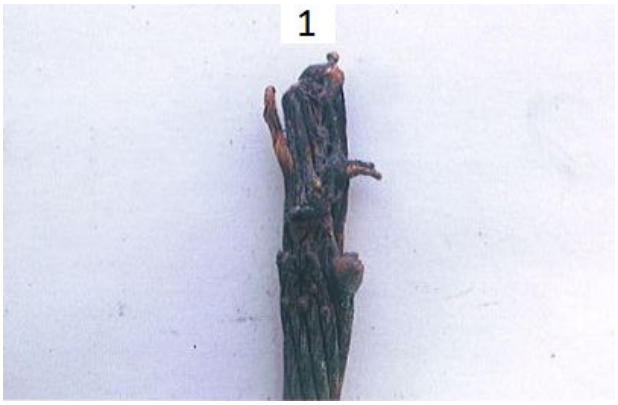


Figure 8 sample

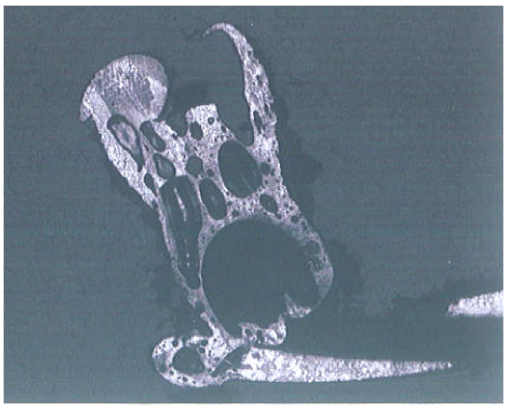


Figure 9 sample 1 metallographic microstructure

According to sample 1 of metallographic microstructure ,we can see that sample1 was short circuit melting scar in fire , so we can eliminated the vehicle fire cause of electrical wire fault, that provided scientific guidance to continue to find the real cause of the fire.

According to melting scar metallographic microstructure can quickly determined whether to electric hot melting scar, but to divide into short circuit melting scar before fire or short circuit

melting scar in fire had the certain difficulty, most of the time the microscopic characteristics and organizational structure of short circuit melting scar before fire and short circuit melting scar in fire didn't presented the typical characteristics, this had higher requirenments to the identification of technical personnel's technical level and practical experience .

5.Summary

The method of metallographic analysis was a widely used authentication method in vehicle electrical fire, at the same time, put forward higher requirements to technical experience level of technical personnel.Based on metallographic microstructure of melting scar to judge short circuit melting scar before fire or short circuit melting scar in fire , combined the exploration situation, vehicle location factors such as fire etc., can quickly confirm the real reason of vehicle fire accurately.

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