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Interpretation of Vehicle Globe Failures: The Unlit Condition

There is little published information on the procedures which should be adopted in examining globes from a vehicle to determine whether they were lit or unlit at the time of an accident. The few which are available (for example, Ref *1*) rely heavily on the chemical and physical changes of the components of a globe. None discusses, in terms of microstructure, the reaction of the components to the stress imposed by the accident. The technique of using chemical changes involves, inter alia, noting oxidation of the tungsten filament and adhesion of glass particles to the filament. These changes are sought as evidence for globes being lit at the time of the accident. These results used in isolation can lead to errors. This paper discusses the microstructure of components in new vehicle globes, how the microstructure changes with use, and the difference in reaction of the microstructure to stress as a function of the globe being lit or unlit at the time of the accident. It is suggested that this information used in conjunction with chemical and physical changes leads to a more reliable conclusion, especially when the globe is unlit.

Components of Vehicle Globes

A vehicle globe consists of a tungsten filament that glows as the result of resistance heating by the passage of a current. The tungsten is prevented from oxidizing by enclosure in a glass envelope within which the atmosphere is inert for a conventional globe or iodine for quartz-iodine globes. While the glass in conventional globes is a soda-lime glass, the glass surrounding the tungsten filament in a quartz-iodine globe is pure silica or quartz. The higher softening point quartz glass is required because the tungsten filament in a quartz-iodine globe operates at a higher temperature (brighter light).

Filaments are normally produced from cold-drawn tungsten wire that has been doped with potassium, aluminum, and silicon. If the wire is heated above the recrystallization temperature, recrystallization and grain growth of the cold-drawn tungsten occurs.

The room temperature properties of tungsten depend on microstructure. Fracture of the cold-drawn microstructure will be by fiber rupture, provided it can be accompanied by delamination [*2*], while the recrystallized microstructure will fracture in a brittle manner by transgranular cleavage, intergranularly, or a combination of the two. Tungsten has a body-centered cubic crystal structure with a transition temperature of approximately 300°C. Thus the mode of fracture of the recrystallized tungsten will depend on temperature. At room temperature (unlit condition) recrystallized tungsten will fail in a brittle manner, while at temperatures above 300°C (lit condition) failure will take place in a ductile manner with necking occurring prior to fracture.

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Experimental Procedure

Several vehicle globes that had been in service were examined under a stereomicroscope. The filaments were broken in half near the center of the coil. One half was mounted in plastic and examined metallographically. The other half was broken at the junction of the tungsten filament and the lead wire by slowly applying a bending moment. These fragments were examined in a scanning electron microscope (SEM). Visual observations were made of the temperature distribution of filaments during operation. Many filaments from vehicles involved in collisions where the conditions of operation of the filament were known were examined both stereomicroscopically and in the SEM.

Results and Discussion

Microstructure of Filament After Service

Figure 1*a* shows part of a vehicle globe that had been in service mounted in clear plastic. The microstructure of the tungsten at Position 1 is exhibited in Fig. 1*b*. It should be noted that the microstructure is one of deformed elongated grains of tungsten typical of the original cold-drawn condition. The microstructure at Position 2, where the wire is leading into the first coil of the coiled section of the filament, is as shown in Fig. 1*c*. Again the microstructure is consistent with one of deformed elongated tungsten grains.

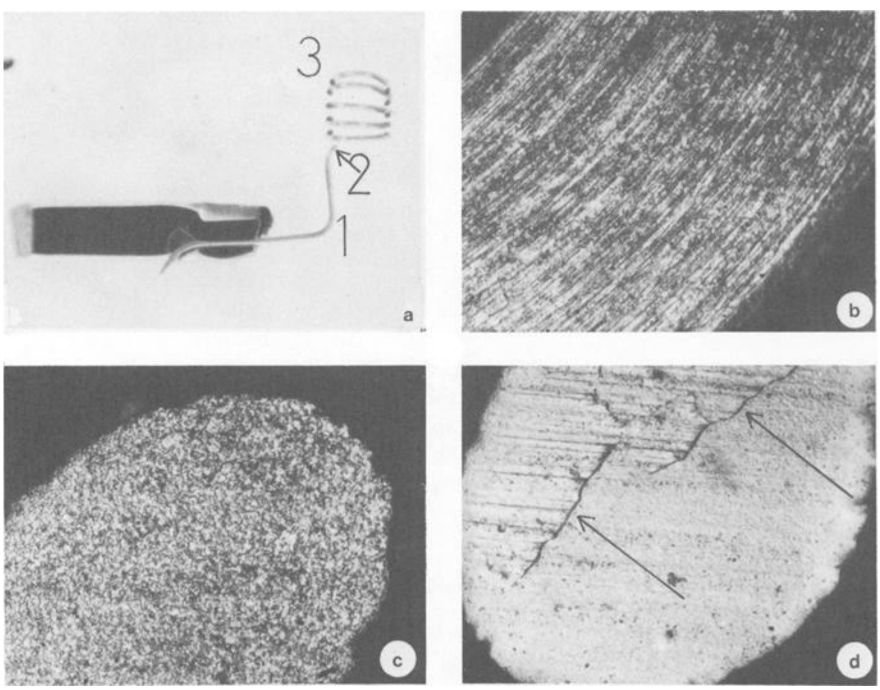

FIG. 1—*Part of a vehicle globe that had been in service.* (a) *Mounted in clear plastic.* (b) *Microstructure of part of the filament shown as Position 1 in* (a); *note the deformed elongated grains of tungsten.* (c) *Microstructure of part of the filament shown as Position 2 in* (a); *note the small cross-sectioned area of elongated grains.* (d) *Microstructure of cross section of the filament within the coil shown as Position 3 in* (a); *note that recrystallization and grain growth have occurred, producing large grains of tungsten.* (*For* b, c, *and* d: *etchant, modified Murakami's reagent*; *magnification, approcimately* × *300*).

In Fig. 1*c* the section of examination is at right angles to the axis of the wire, the so-called cross section, while the section of Fig. 1*b* at Position 1 is parallel to the axis of the wire, the longitudinal section. In Fig. 1*c* each of the black lines is a grain boundary, that is, a boundary between a grain or crystal and its immediate neighbors. By contrast the cross section of the grains is large at Position 3 in Fig. 1*a*. This is depicted in Fig. 1*d*, where a grain boundary is marked with arrows. All the wire to the bottom and right of that boundary is one grain.

The reason for this variation of grain shape and size is understood when the temperature variations within a filament are studied (Fig. 2). When a filament in a conventional globe is lit, only the coil glows, the straight part of the filament between coil and lead wire being cooled by conduction to the lead wire and possibly by convection. Since only the coiled part glows, only this part can exceed the recrystallization temperature for tungsten. This is shown schematically in Fig. 3. Since only the coil exceeds the recrystallization temperature, the straight part between coil and lead wire does not recrystallize and this is the explanation for the variations in microstructure shown in Figs. 1*b*, *c*, and *d*.

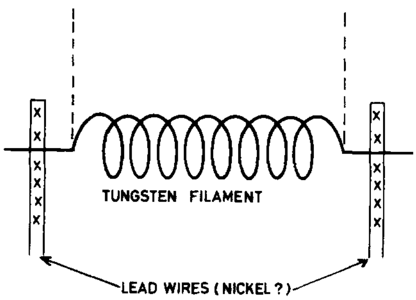

FIG. 2—*Schematic diagram of temperature variation within a lit filament. Only the coil glows when the globe is lit.*

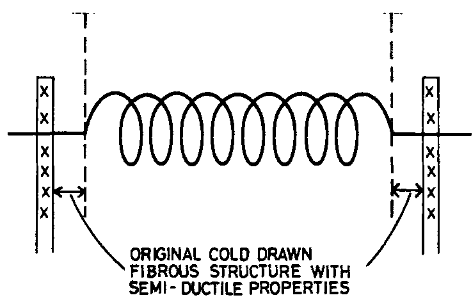

FIG. 3—*Schematic diagram showing how recrystallization occurs only within the coil of the filament, increasing brittleness.*

Filaments Fractured in the Laboratory

A portion of the other part of the filament of Fig. 1 is shown in Fig. 4 as it appeared in the SEM. The brittle nature of the fracture in the bottom left-hand corner of Fig. 4*a* is shown at a higher magnification in Fig. 4*b*. The nature of the fracture at the other end of the coil of Fig. 4 where the filament joins the lead wire is shown in Figs. 5*a*, *b*, and *c*. The semiductile nature of the fracture with attendant delamination is shown most clearly in Fig. 5*c*.

General Characteristics of Filament Failures From Vehicle Accidents

With respect to the microstructure of a tungsten filament in service, it is possible to describe in a general manner the type of failure which occurs in an accident and hence deduce whether the filament was lit or not.

Lit Filament

If the glass envelope is broken with resulting yellowish-white tungsten oxide and adhering glass beads, there can be no doubt that the filament was lit if the filament is distorted. If the glass envelope is not broken, distortion of the tungsten filament will

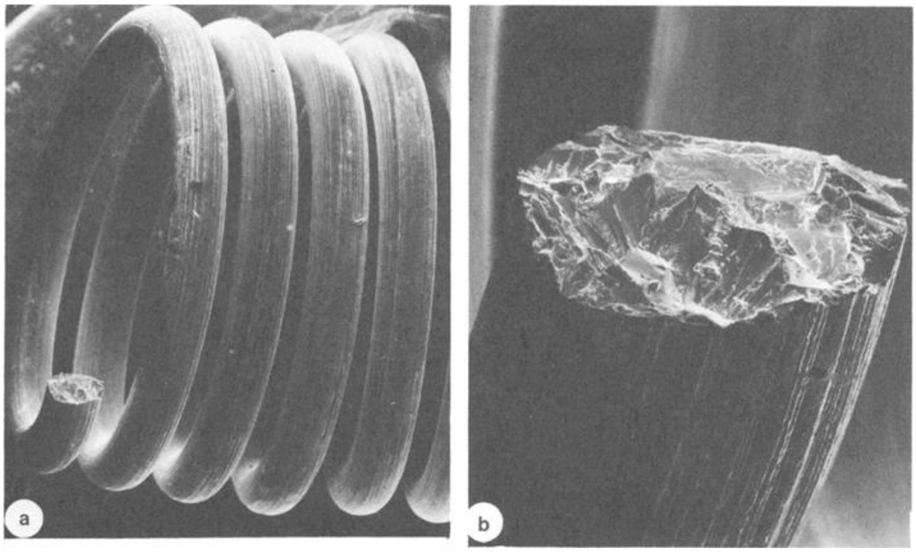

FIG. 4—*Scanning electron micrographs of coil from filament that had been in service and subsequently broken in the laboratory*; (a) *magnification, approximately* ×*35*; (b) *fracture surface in bottom left-hand corner of* (a) *at higher magnification* (*approximately* ×*235*) *showing brittle nature of fracture and detail of drawing lines on the surface of the wire.*

indicate whether the filament was lit; a large change in momentum produces a fracture with tapered ends, as depicted schematically in Fig. 6 for a case of the change in momentum being at right angles to the axis of the coil.

Unlit Filament; No Direct Contact of Globe with Other Objects

When a vehicle is suddenly decelerated during a collision inertia will tend to keep the coil moving, thus producing a bending moment. As a result, brittle fracture (as shown in Fig. 4*b*) may occur near the junction of the coil and the straight section when recrystallization has occurred. The magnitude of the stress varies as the magnitude of deceleration. Although the bending moment and hence the stress will be a maximum in the straight section adjacent to the lead wire, fracture will not occur since an original cold-drawn fibrous microstructure with semiductile mechanical properties persists at that position. The response of an unlit filament to deceleration during a collision is summarized schematically in Figs. 7*a* and *b*.

Unlit Filament; Direct Contact of Globe with Other Objects

Bending moments producing stress may occur as the result of a combination of deceleration and contact with objects. Under these conditions the lead wires are usually deformed, and fracture may occur at the junction of the straight section of the filament and the lead wire. Figure 8 is a schematic diagram of an idealized situation where both leads have made contact with an object and fracture has occurred at the juction of the filament and lead wire.

Fracture occurs under the rapid application of a bending stress. Under these conditions fracture is initially by cleavage, but this is arrested by delamination (Fig. 9) and

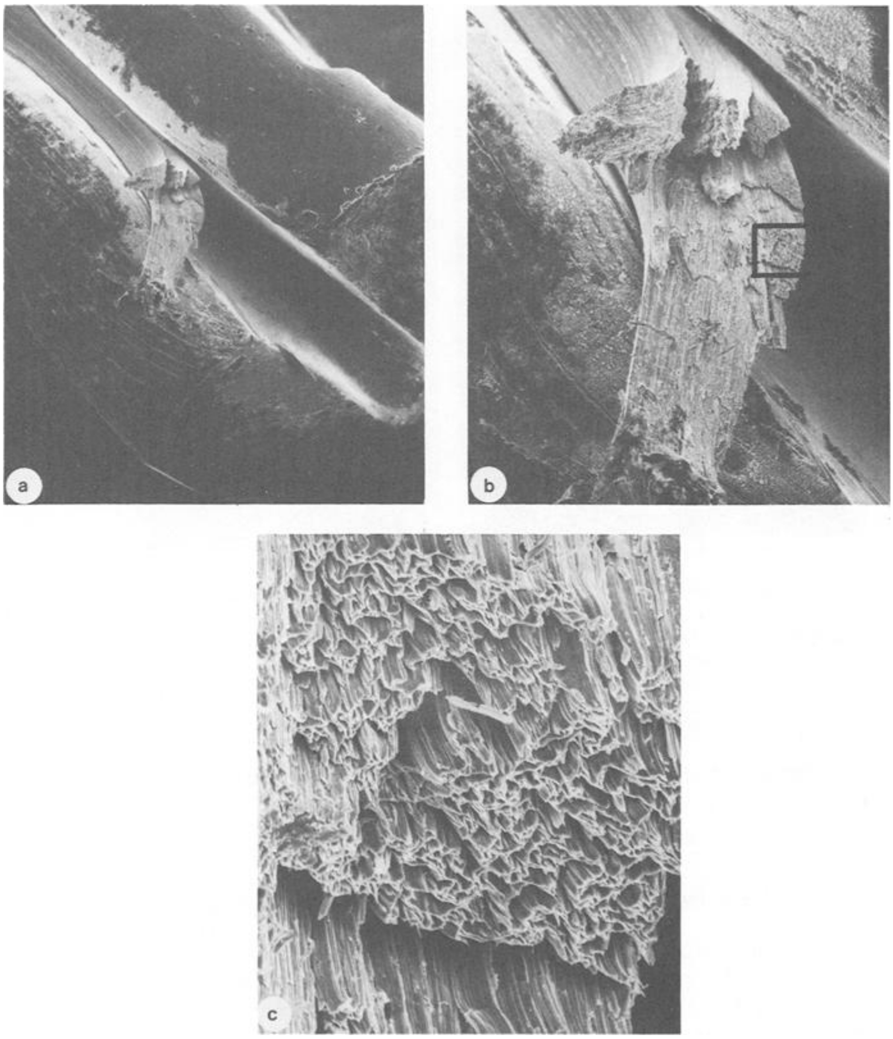

FIG. 5—*Scanning electron micrographs of fracture of coil at junction of straight part of filament and lead wire under slow bending*; (a) *magnification, approximately* ×*35*; (b) *magnification, approximately* ×*110*; (c) *boxed section of* (b) *at magnification of approximately* ×*1100 showing semiductile nature of fracture with attendant delamination.*

is in conformity with the results of Stokes and Li [3] and Gilbert [4]. Figure 9 shows how fracture was initiated on the right-hand side of the straight section of the filament at the junction with the lead wire and how delamination has arrested the brittle fracture after approximately 60% of the diameter had been separated in this manner.

Possible Errors in Interpretation

An error in evaluating a vehicle globe is most likely to occur if the glass envelope is missing. Since fracture by mishandling a distorted filament lit at the time of the accident will produce the same results as fracture in the unlit condition, this possibility can be

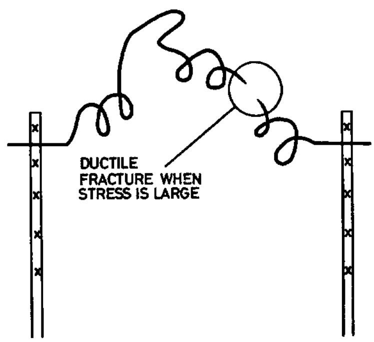

FIG. 6—*Schematic diagram of a coil lit when vehicle decelerated during collision at right angles to the axis of the coil.*

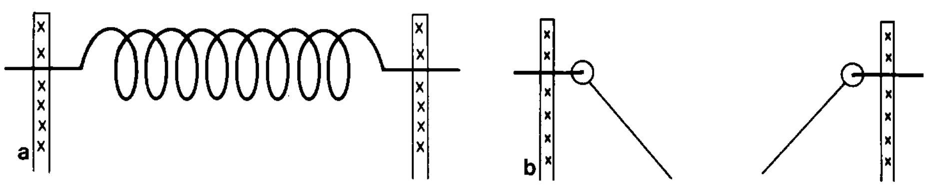

FIG. 7—*Coil unlit when vehicle decelerated during collision*; (a) *no change when stress is small and* (b) *brittle fracture at junction of coil and straight section when stress is large.*

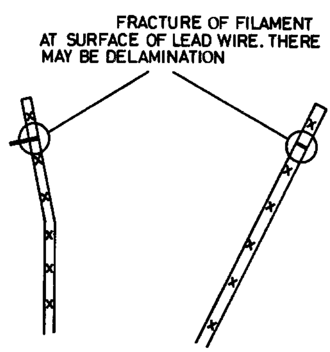

FIG. 8—*Coil unlit at time of collision and globe made contact with another object. This is an idealized situation where both leads have made contact with an object and fracture has occurred at the junction of the filament and lead wire.*

avoided by photographing filaments in situ before removal for laboratory examination [5]. Surface discoloration of the straight section of the tungsten filament as the result of oxidation can occur in service. It has been found in new globes as a result of the heat of welding the filament to the lead wire. Thus surface discoloration of the straight section cannot be taken as evidence for the filament being lit. Since the straight section of the filament retains its semiductile properties, glass particles will indent and adhere. In addition, since the operating temperature of the straight section is much less than the

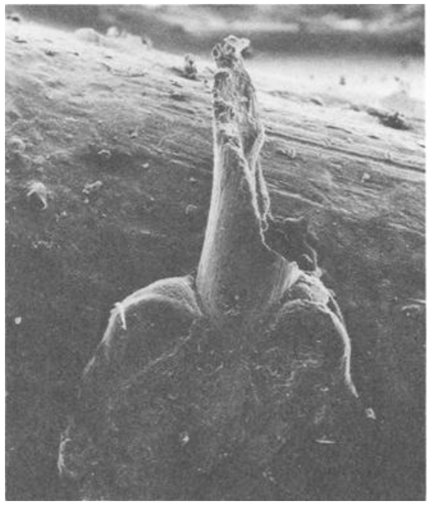

FIG. 9—*Scanning electron micrograph of unit filament that has come into contact with another object during collision. Fracture has initiated at the right side by cleavage but this has been arrested by delamination (magnification, approximately* × *75).*

coil, the possibility of the glass particles becoming globular is much reduced. Therefore the presence of glass particles on the straight section of the coil is difficult to interpret.

Conclusions

1. A variation of microstructure results from a variation in operating temperature of the filament of conventional globes; normally, only the coiled portions glow during operation.
2. Although filaments are produced from cold-drawn fibrous tungsten, during service only the coiled portion of the filament exceeds the recrystallization temperature and hence undergoes recrystallization and grain growth.
3. As a result of a variation in microstructure between coiled and straight portions of the filament, each responds differently to an applied stress. This difference can be used to determine whether the filament was unlit at the time of the collision. If the stress is high, brittle fracture occurs within the coil or where recrystallization finishes within the straight section. If the stress is low, no change occurs and other globes from the vehicle must be examined. Fracture of the straight section, usually adjacent to the lead wire, occurs initially by brittle fracture and finally by delamination when the globe contacts an object during the accident.

Summary

The microstructure of filaments of vehicle globes that have been in service has been determined and related to the temperatures attained during operation. As a result of a variation in microstructure between coiled and straight portions of the filament, each responds differently to an applied stress. This difference can be used to determine whether the filament was unlit at the time of the collision. If the stress is high, brittle fracture occurs within the coil or where recrystallization finishes within the straight section. If the stress is low, no change occurs and other globes from the vehicle must be examined.

Fracture of the straight section, usually adjacent to the lead wire, occurs initially by brittle fracture and finally by delamination when the globe contacts an object during the accident.

Acknowledgment

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References

[*1*] Dolan, D. N., "Vehicle Lights and Their Use as Evidence," *Journal of the Forensic Science Society,* Vol. 11, No. 2, 1971, pp. 69–82.
[*2*] Lee, D., "Fracture of Drawn Tungsten Wires," *Metallurgical Transactions,* Vol. 6A, No. 11, 1975, pp. 2083–2088.
[*3*] Stokes, R. J. and Li, C. H., "The Notch-Impact Behavior of Tungsten," *Transactions of the Metallurgical Society of A.I.M.E.*, Vol. 230, No. 5, 1964, pp. 1104–1110.
[*4*] Gilbert, A., "A Fractographic Study of Tungsten and Dilute Tungsten-Rhenium Alloys," *Journal of Less-Common Metals,* Vol. 10, No. 5, 1966, pp. 328–343.
[*5*] Severy, D. M., "Headlight-Taillight Analysis from Collision Research," in *10th STAPP Car Crash Conference,* Society of Automotive Engineers, New York, 1967, pp. 14–37.

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