Australian Government
Department of Defence
Defence Science and
Technology Organisation

Guide to the Impact Behaviour of Aircraft Instrument Panel Lamp Filaments

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Defence Science and Technology Organisation

DSTO-TR-2217

ABSTRACT

In the event of an aircraft experiencing an impact that causes significant structural damage, the examination of lamp filaments from the instrument panel warning and caution system has provided investigators with valuable information regarding the status of the aircraft systems at the time of impact. This report presents the results of lamp tests conducted at medium to high *g* impact and covers the filament condition prior and post impact, on new and aged filaments. It also provides guidelines for determining if a lamp was active just prior to the impact.

Published by

Air Vehicles Division
DSTO Defence Science and Technology Organisation
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Fishermans Bend, Victoria 3207   Australia

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AR-014-338
October 2008

Guide to the Impact Behaviour of Aircraft Instrument Panel Lamp Filaments

Executive Summary

The damage incurred by incandescent lamps used for the warning and caution system in aircraft provides investigators valuable information regarding the status of the aircraft immediately prior to a major accident. Tests simulating impact at various *g* levels on new and aged lamps in both incandescent and non-incandescent states showed that some useful information can be derived.

After initial filament examination a comparison was made against the new and the aged filaments of two types of lamps to determine their variations. Lamps of each category were then impact tested at two different *g* levels while either incandescent or non-incandescent. Examination of the filaments was then used to determine factors which could distinguish the category to which the samples belonged.

The results from this analysis provide additional information to accident investigators in their evaluation of an accident by enabling them to ascertain whether a warning or caution lamp was active just prior to an impact.

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Bruce Grigson, APS Level 6, Science & Technology Level 4.

In 1976 he began work at the Ammunition Factory Footscray where he completed a Trade Certificate in Fitting & Machining and also Toolmaking.

In 1981 he commenced work for the 3rd Army Quality Assurance Unit later known as the Defence Quality Assurance Organisation, performing complex dimensional examinations in the field of defect and failure investigations, reverse engineering of components and general engineering Metrology. In 1982 he graduated from Footscray Technical College having obtained a Certificate of Technology in Production Engineering.

In 1994 he accepted a position at the Regional Superintendent Navy Engineering Support Melbourne as the Head of Section Gauges, responsible for the repair and calibration of ordnance & explosive ordnance gauges for the fleet.

In 1999 he transferred to DSTO Melbourne Air Vehicles Division (formerly Airframes and Engines Division) where he continues working in the area of dimensional metrology and ad-hoc mechanical testing. Recently he has been involved in the metrological analysis of the N16-100 Seaking accident investigation, P3 Orion upper drag strut and mechanical testing of Chinook fire extinguisher brackets.

Contents

Nomenclature

AFE	Aircraft Forensic Engineering
AVD	Air Vehicles Division
DC	Direct Current
DSTO	Defence Science and Technology Organisation
F	Fahrenheit
FFT	Fast Fortran Transform
g	Force of Gravity
Hrs	Hours
Hz	Hertz
ID	Identification
kHz	Kilohertz
mA	Milliampere
mm	Millimeter
ms	Millisecond
mV	Millivolts
NATO	North Atlantic Treaty Organisation
NLR	Nationaal Lucht-en Ruimtevaartlaboratorium *National Aerospace Laboratory (The Netherlands)*
SEM	Scanning Electron Microscope
RAAF	Royal Australian Air Force
rms	Root Mean Square
V	Volts
WOFF	Warrant Officer
µm	Micrometer

1. Introduction

Aircraft cockpit annunciator panel and caution lights, Figure 1, illuminate to warn the crew of equipment malfunctions or other conditions. In the event of an aircraft being involved in an accident, analysis of these lamps can provide the investigator with vital information in determining the operating condition of the aircraft and its systems immediately prior to the accident, and through assessment, a qualitative appreciation of the severity of the impact.

In this study, three hundred and twenty aircraft cockpit lamps were aged and impact tested to assess the condition of the filaments of these lamps in both the "cold" and "hot" condition following laboratory-controlled impact testing at various accelerations.

The criteria against which the filaments were evaluated were assessed from the following.

- new or aged,
- incandescent or non-incandescent and,
- acceleration

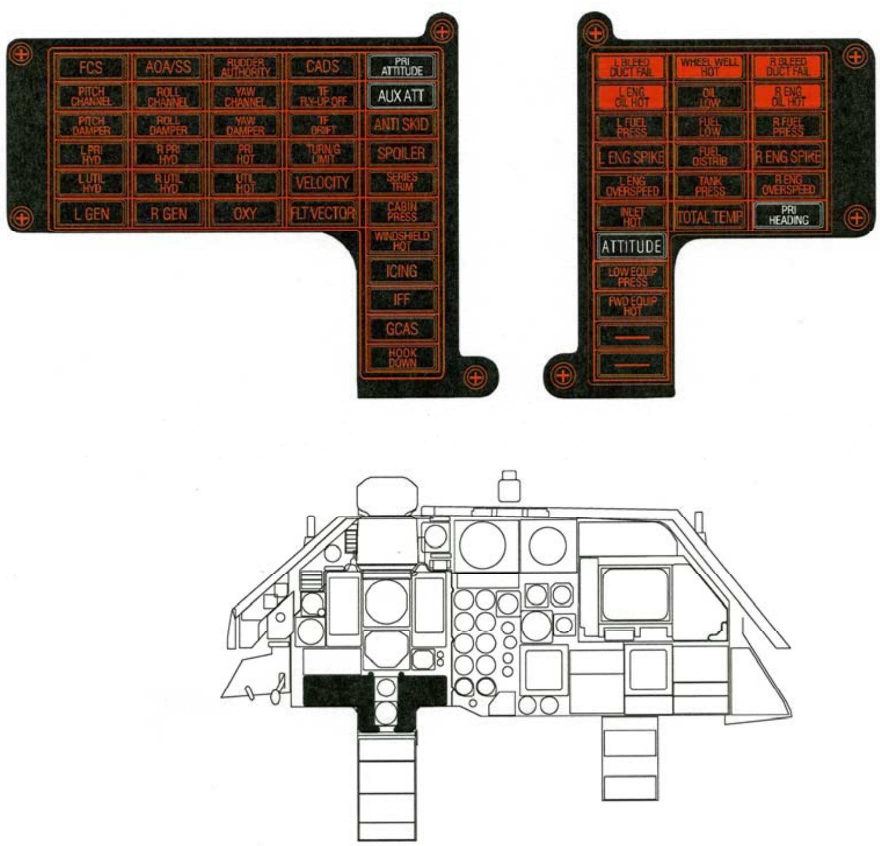


Figure 1 Example of an aircraft cockpit and caution panels

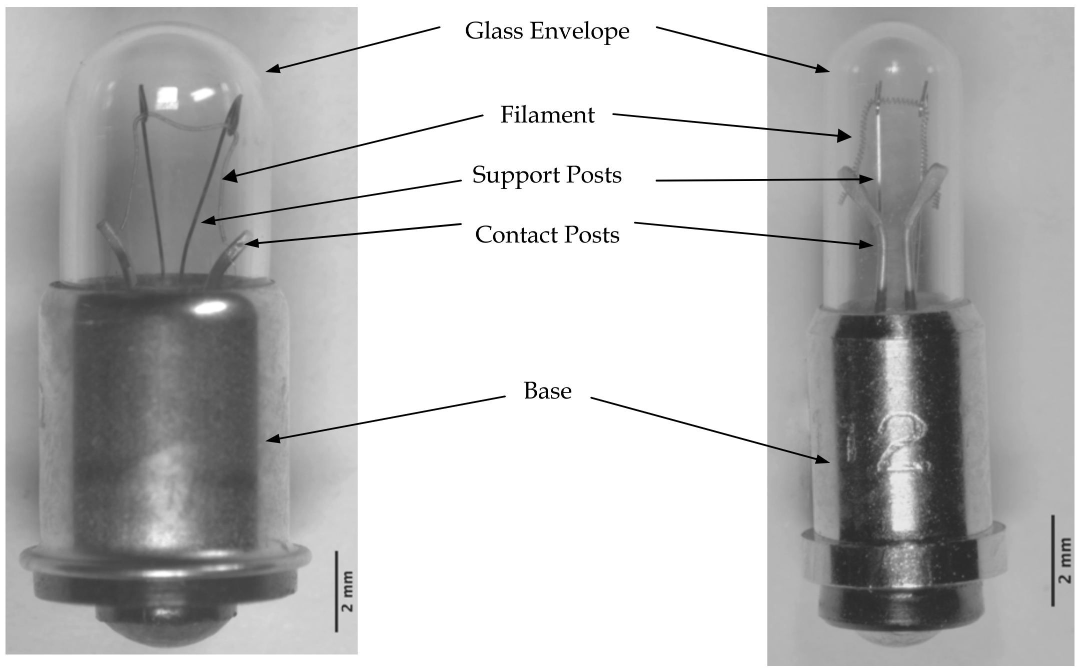
2. Test Specimens

The lamps used to illuminate the caution and warning lamps vary in size and shape for the diverse range of aircraft in service. For this research two types of lamps were tested. The lamps selected are from Royal Australian Air Force (RAAF) PC-9/A trainer aircraft. These were chosen due to a ready source of supply via the Defence Supply system. Lamp details and description are given in Table 1 & Figure 2.

Table 1 Test specimens

Description	Lamp Parameters	
	Type 1	Type 2
Nato stock number	6240-00-763-7744	6240-14-380-8964
Manufacturer	Chicago Miniature	Oshino Wamco
Base	Midget flange Dia. 7.2mm	Sub Midget flange Dia. 4.5mm
Bulb	T-1 ¾	T-1
Wire[1]	C-2F Single Coil	CC-2F Coiled Coil
ID Marking on base	CM 387Q	OL-3112
Voltage (V)	28	28
Current (mA)	40	24
Average life[2] (hrs)	10000	5000

1 - Filament shape reference MIL-DTL-6363H.
2 - Obtained from the manufacturer specification.



A: Typical Type 1 lamp 28V 40mA ***B: Typical Type 2 lamp 28V 24mA***

Figure 2 Type 1 and Type 2 lamps

3. Lamp Design

Illumination lamps have a tungsten filament coil with a wire diameter matched to the electrical current and power rating. The appropriate current running through the coil causes the coil temperature to rise to 2200 °Celsius resulting in a bright white light. Tungsten at incandescent temperatures and exposed to the air, will rapidly oxidize. To prevent oxidation, the filament is hermetically sealed within a glass envelope in an environment of an inert gas such as nitrogen [1].

A filament in a new lamp consists of tightly evenly spaced coils running between two upright support posts. In most new lamps the filament has a bright lustre.

The 28 volt lamps, Types 1 & 2 used in this investigation have different filament designs. Type 1 lamps comprise a single coil filament, wire diameter of 10.5 μm and have a designed current flow of 40 mA. Type 2 lamps, have a double helix filament, wire diameter of 8.1 μm with a designed current flow of 24 mA. See Figure 3 & Figure 4 for lamp profiles. Filament wire diameter measurements were determined from Scanning Electron Microscope (SEM) images and are approximate.

Both lamp types in new condition were viewed on an optical profile projector magnified 50 times and it was observed that Type 1 lamp filaments sag slightly between the support posts whereas Type 2 lamp filaments are straight. The amount of sag between the two lamp types was measured, since it may have been a source of confusion when evaluating a lamp after impact damage. See Tables A-1 & A-2 for the sag dimensional measurements and Figures B-1 though to B-4 and C-1 through to C-4 for the filament profiles.

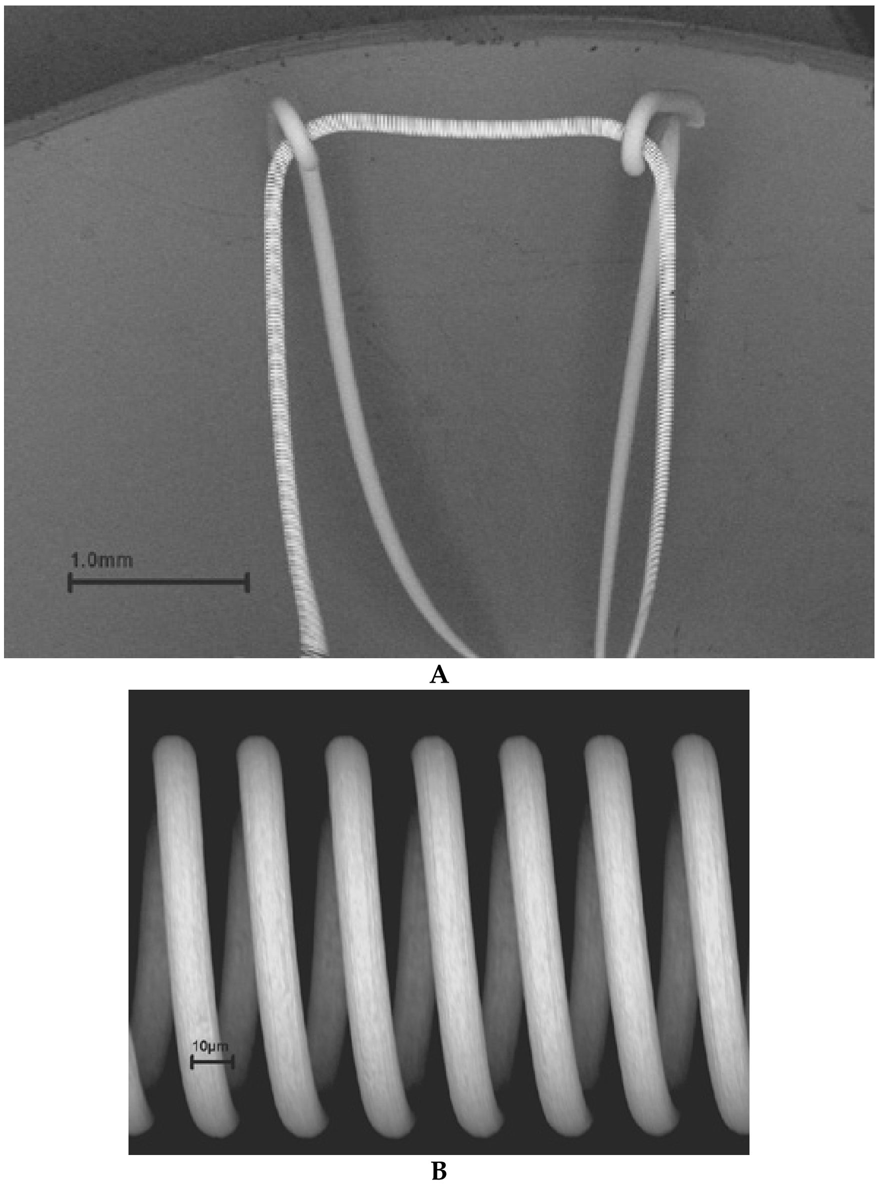
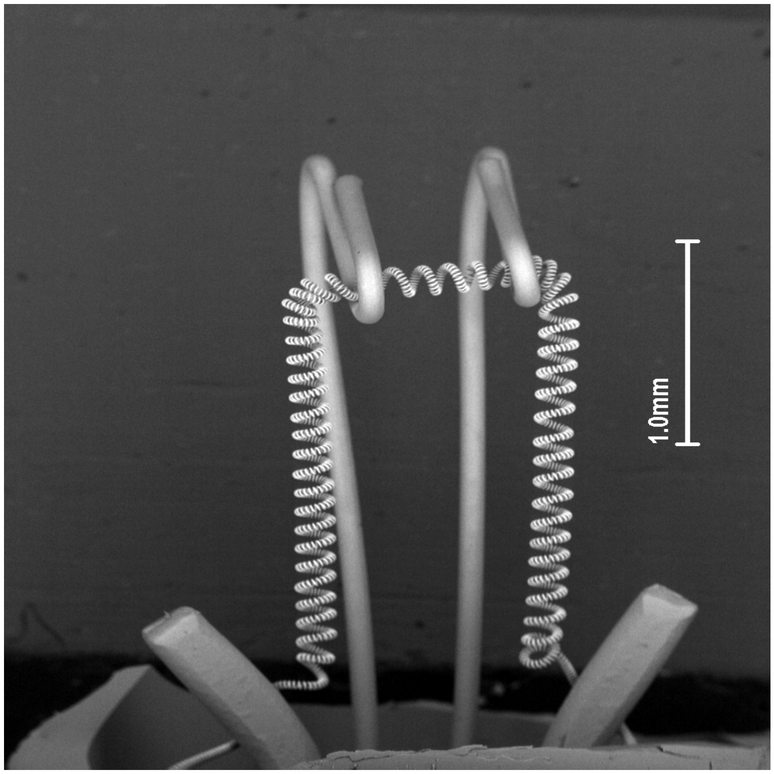
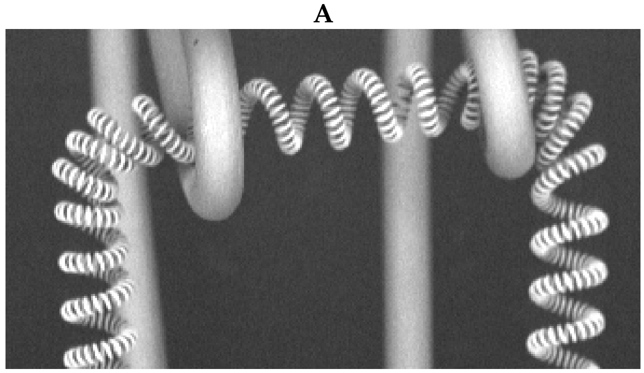


Figure 3 (A) Type 1 lamp filament. (B) Closer view of Type 1 filament.



A



B

Figure 4 (A) Type 2 lamp filament. (B) Closer view of the Type 2 filament showing the double helix profile.

4. Ageing of Lamps

Lamps used in this research were aged for 0, 10, 50, 100 and 500 hrs to emulate effect of the age in service. 160 lamps of each type were acquired and divided into 10 groups of 16 lamps. Half were assigned for hot (Incandescent) testing and the other 5 groups used for cold (Non-incandescent) testing. Lamps were not aged beyond 500 hours since severe filament notching[1] occurs at this level. When combined with extremely high impact conditions, this combination may produce unreliable filament failures.
It was noted that:

- As part of the manufacturers' quality control inspections, some or all lamps may have been previously exposed to a current flow for an indeterminate time.
- This research will assume that all lamps were received with no ageing.
- The term "Hot" means incandescent when drop tested.
- The term "Cold" means no current applied when drop tested.
- Selection of 16 lamps per group allowed for drop testing 2 groups of 8 specimens in 4 orientations with a minimum of two-drop heights.

4.1 Method used for ageing

To accommodate both lamp types for ageing and also later drop testing, two separate aluminium test panels were designed, manufactured and electrically wired by DSTO. Each panel allowed the fitting of 16 lamps. Suitable lamp holders were acquired and fitted to both panels to provide rigid support for the lamps. To power the lamps a compact portable Mason Ep-613 series 0-30 Volt DC regulated power supply was used (Figure 5).

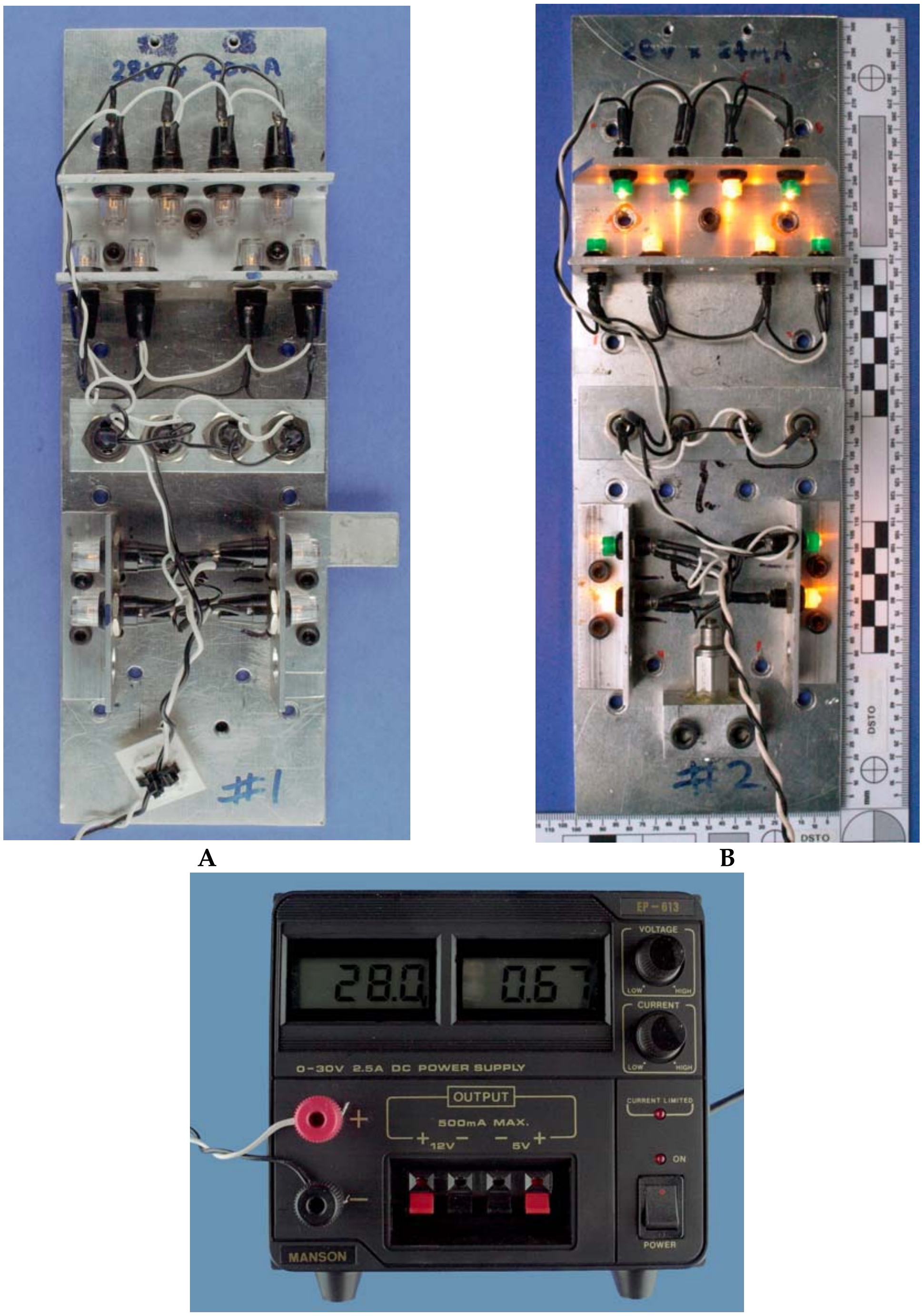
Each group of 16 lamps fitted to the panels, was aged simultaneously in four different orientations in preparation for drop testing as shown in Figure 5. All lamps were subjected to a constant supply of 28 volt DC. From this procedure 320 lamps in total were aged in 20 groups with a failure rate of less than 2%. Most of the failures occurred towards the higher ageing times as revealed in Table 2.

Table 2 Failures for discrete ageing times without drop test

Lamp	Current mA	Failures after Ageing Time				Total Failures
		10 hr	50 hr	100 hr	500 hr	
Type 1	40	0	0	0	2	2
Type 2	24	1	1	1	1	4

Normal filament burnout was assumed to be the reason for the failures and a detailed analysis was not performed to determine the exact cause.

[1] Tungsten ions begin to migrate within the filament to preferred crystal planes; this is visible as notching. [4]



A B

C

Figure 5 Lamp panels (A) 28V 40mA lamps (Type 1 Lamps). (B) 28V 24mA lamps (Type 2 Lamps). (C) Power supply.

4.2 Effect of ageing

The filament characteristics during ageing were observed in detail using a Scanning Electron Microscope (SEM). For both lamp types when new, the SEM images showed parallel longitudinal draw marks along the full length of the filament wire. It would appear that these marks were established at the filament manufacturing stage, when drawing the wire through a die. Refer to Figures Figure 6 & Figure 11 for SEM images of filament surface condition.

For lamp groups that were conditioned at 28 volts DC from 10 to 500 hours, the sequence of damage commenced with a scaled surface, preceded to the onset of notching with sagging, followed by pronounced notching. Refer to Figures Figure 6a to Figure 15b for SEM images of this process.

At each stage of ageing, deformities developed over the entire filament length with reduced damage occurring near the contact and support posts which probably acted as a heat sink and reduced surface temperatures.

Referring to Table A-1 for Type 1 lamp sag, it can be seen that, when the lamps are new the filaments have minimal sag. Measured mean value of sag for each group 0.016 mm & 0.018 mm.

It can be seen that heat produced during operation of the wire increases sagging. Comparing the amount of sag for lamps conditioned at 10 to 500 hours, there is little difference between them. Mean values ranged from 0.201 mm to 0.258 mm and referring to Table 3 below, the amount of sagging does not increase uniformly with ageing time after its initial effect.

Table 3 Mean filament sag for Type 1 lamps without drop testing for specified ageing times

Ageing Time hours	Mean Sag mm	
	Hot	Cold
0	0.018	0.016
10	0.258	0.210
50	0.238	0.226
100	0.251	0.234
500	0.201	0.241

Therefore, it would seem that the applied heat at the filament caused similar elongation of the tungsten wire irrespective of the ageing time. Additionally, although the lamps were held in different orientations, the sag direction was always towards the lamp base (downward) for the overall age-tested groups.

For Type 2 lamps there was no change in the filament profile from new and after the ageing phase, see Table A-2 for details. The double helix filament profile and closer spacing between the support posts may have an influence on the filament strength.

Normal lamp failure occurs due to evaporation of the tungsten filament when incandescent. This produces localised pitting so that the filament becomes thinner and weaker in certain locations along the filament. These narrower locations have greater electrical resistance so that the current through the filament further increases the temperature making them even hotter. When the filament temperature at the narrowest point reaches the melting point of tungsten 3370 ºC, the filament will break. An electrical arc forms across the gap and the lamp flares up brightly for an instant until the gap widens enough to stop the current flow. The lamp is then burned out. Rounded or ball ends to the filament provide evidence for this process [1].

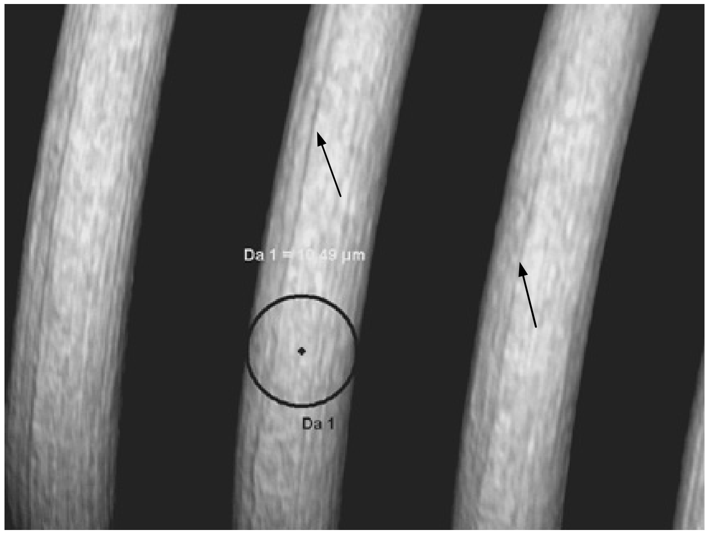
To create a high magnification image of the filaments, the glass envelope was carefully removed from the lamp and viewed using a scanning electron microscope (SEM). Only one lamp from each cold group was used for this examination.

All failed lamps including those used for the SEM images were replaced with equivalent aged lamps; therefore the required numbers for drop testing was maintained.

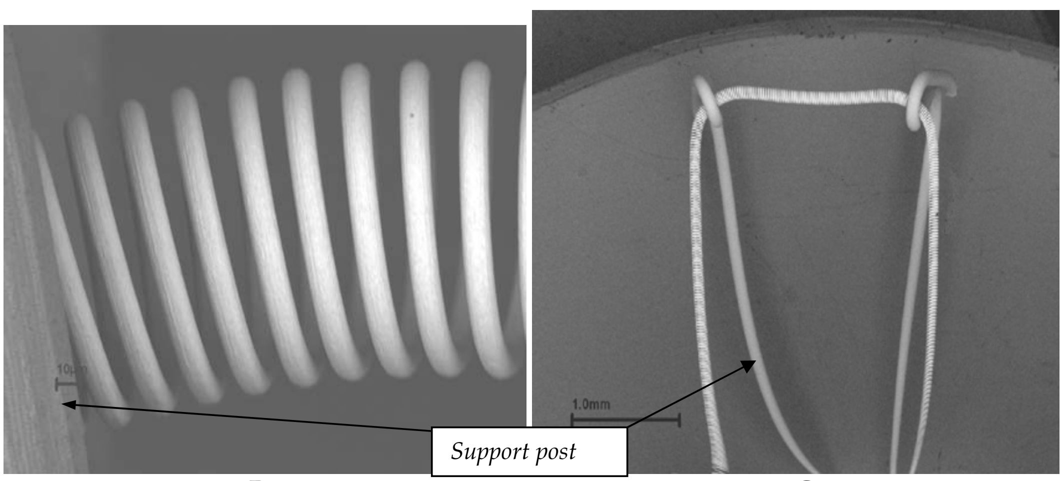
Figure 6 through to Figure 15 show SEM images of the filament after ageing for different ageing times.

Tables A-1 & A-2 in show the measured filament sag value for different ageing times.

4.2.1 Type 1 (28V 40mA) lamp filament images



A



B **C**

Figure 6 *(A) Mid area of filament arrows indicate longitudinal draw marks on Type 1 lamp with no ageing. (B) Filament near support post for Type 1 lamp with no ageing. (C) No appearance of filament sag for Type 1 lamp with no ageing.*

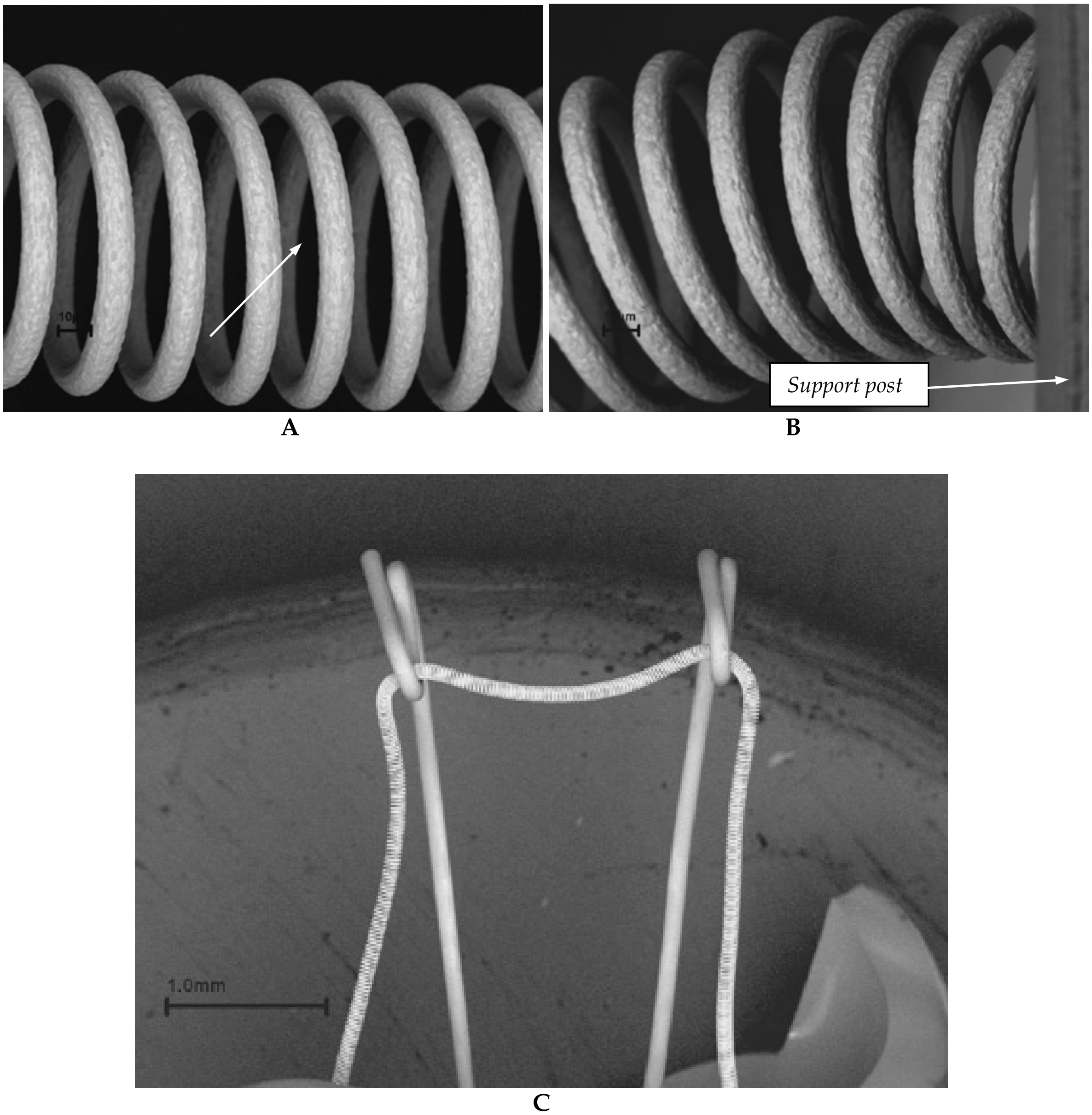


Figure 7 *(A) Arrow indicates scaling on mid area of filament for Type 1 lamp aged for 10 hours. (B) Scaling continues through and beyond the support posts for Type 1 lamp aged for 10 hours. (C) Commencement of filament sag starts on Type 1 lamp aged for 10 hours.*

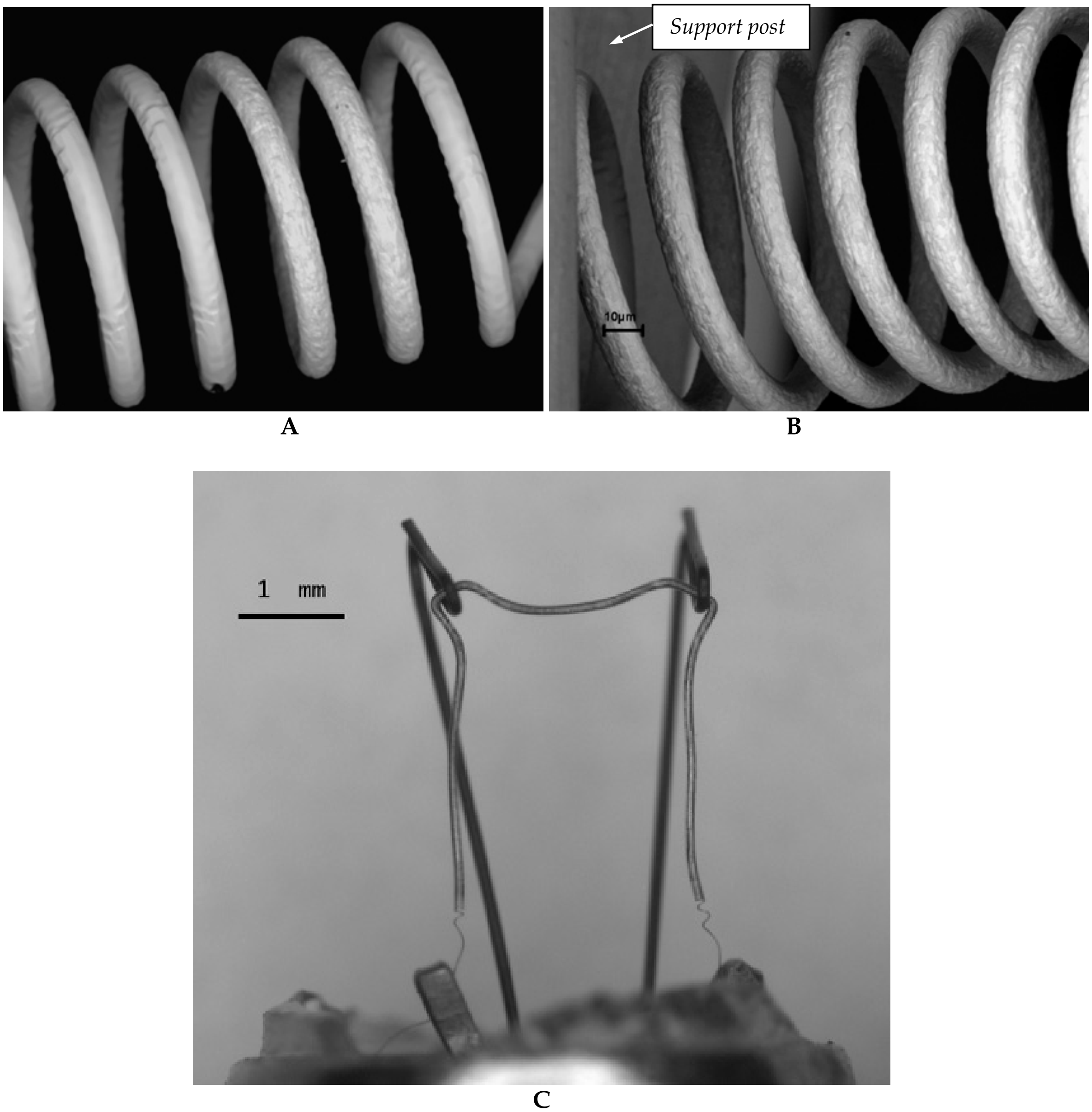


Figure 8 *(A) Blend of scale and notching, mid area of filament on Type 1 lamp aged to 50 hours. (B) Only scale (No notching) near support post on filament of Type 1 lamp aged to 50 hours. (C) Filament sag on filament of Type 1 lamp aged to 50 hours.*

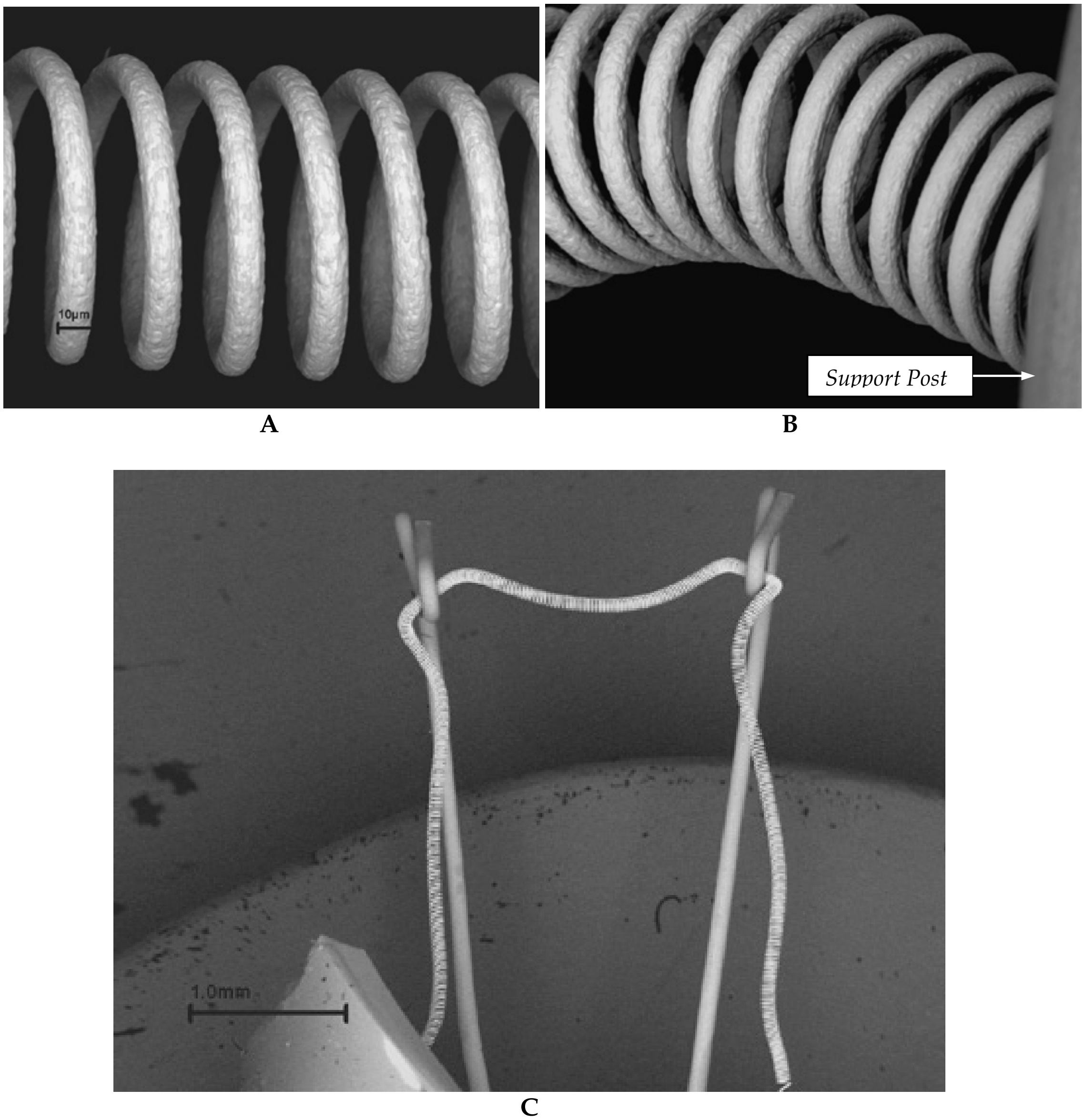


Figure 9 *(A) Mid area of filament showing scale converting into notching for Type 1 lamp aged to 100 hours. (B) Scale only (No notching) near support post of Filament of Type 1 lamp aged to 100 hours. (C) Filament sag for lamp Type 1 lamp aged to 100 hours.*

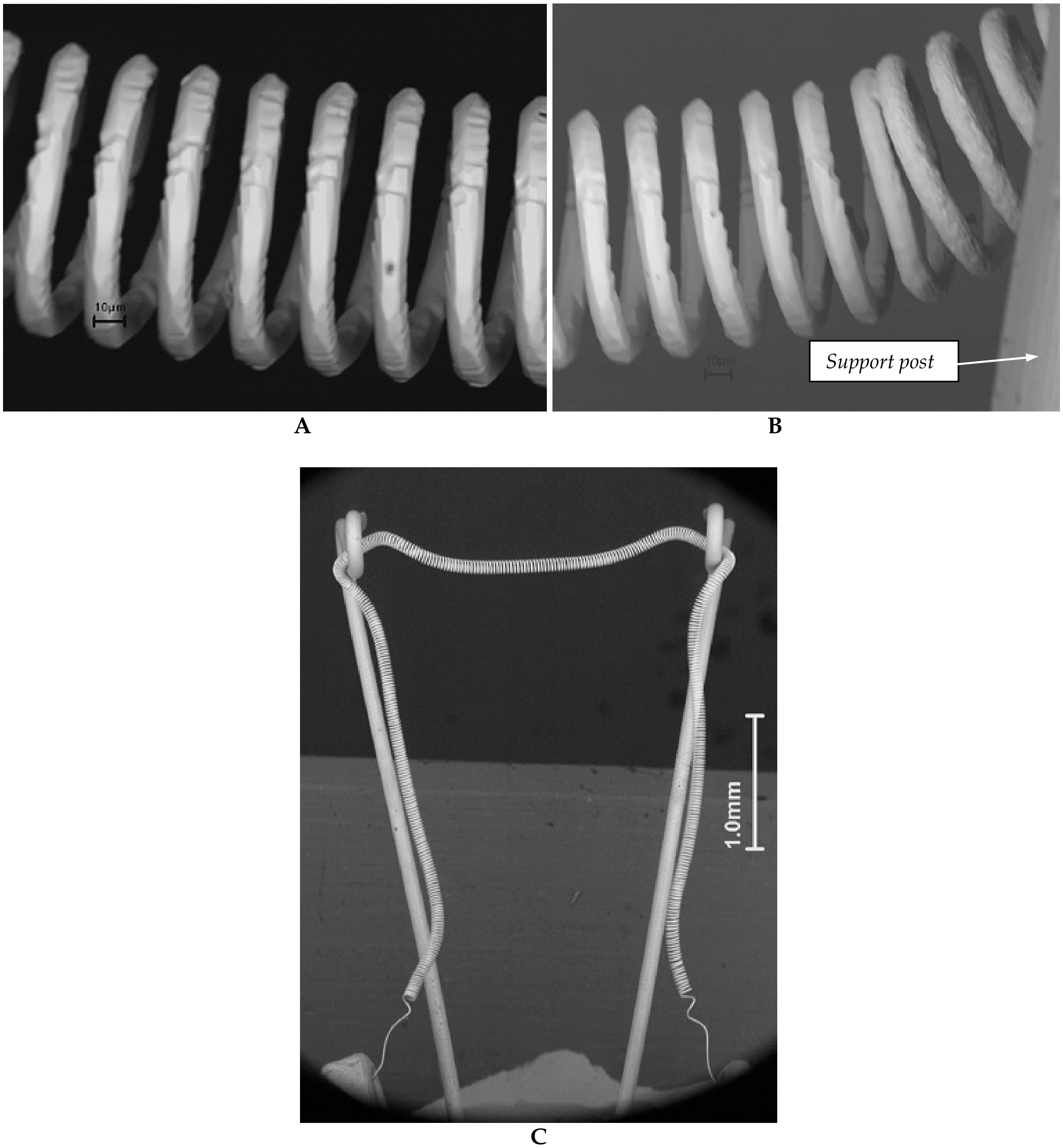


Figure 10 (A) Mid area of filament, show heavy notching for Type 1 lamp aged to 500 hours. (B) Scale only (No notching) near support post for a Filament of Type 1 lamps aged to 500 hours. (C) Filament sag for Type 1 lamp aged to 500 hours.

4.2.2 Type 2 (28V 24mA) lamp filament images

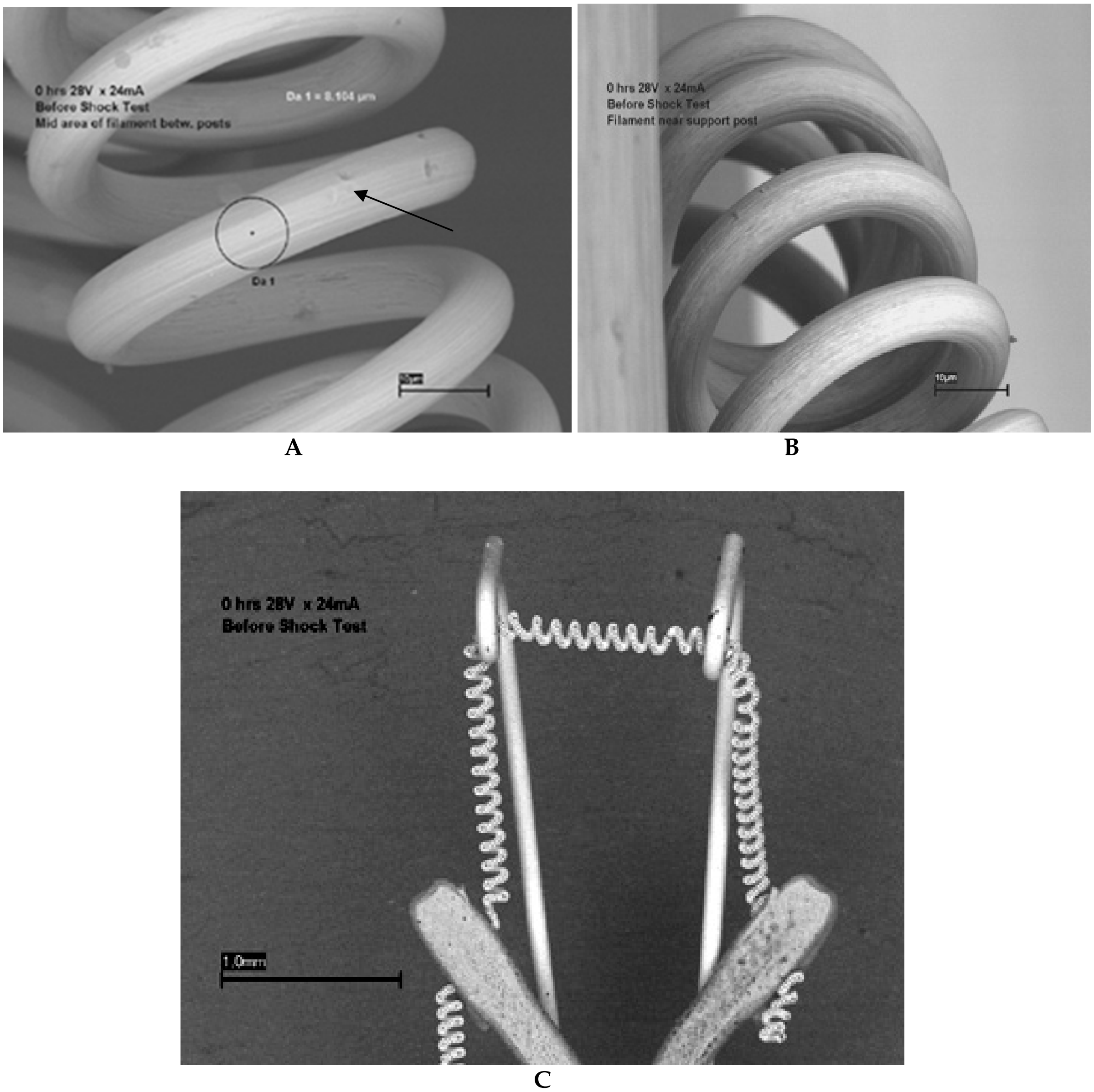


Figure 11 (A) Mid area of filament, showing longitudinal draw marks for a Type 2 lamp with no ageing. (B) Filament near support post of a Type 2 lamp with no ageing. (C) No filament sag evident for Type 2 lamp with no ageing.

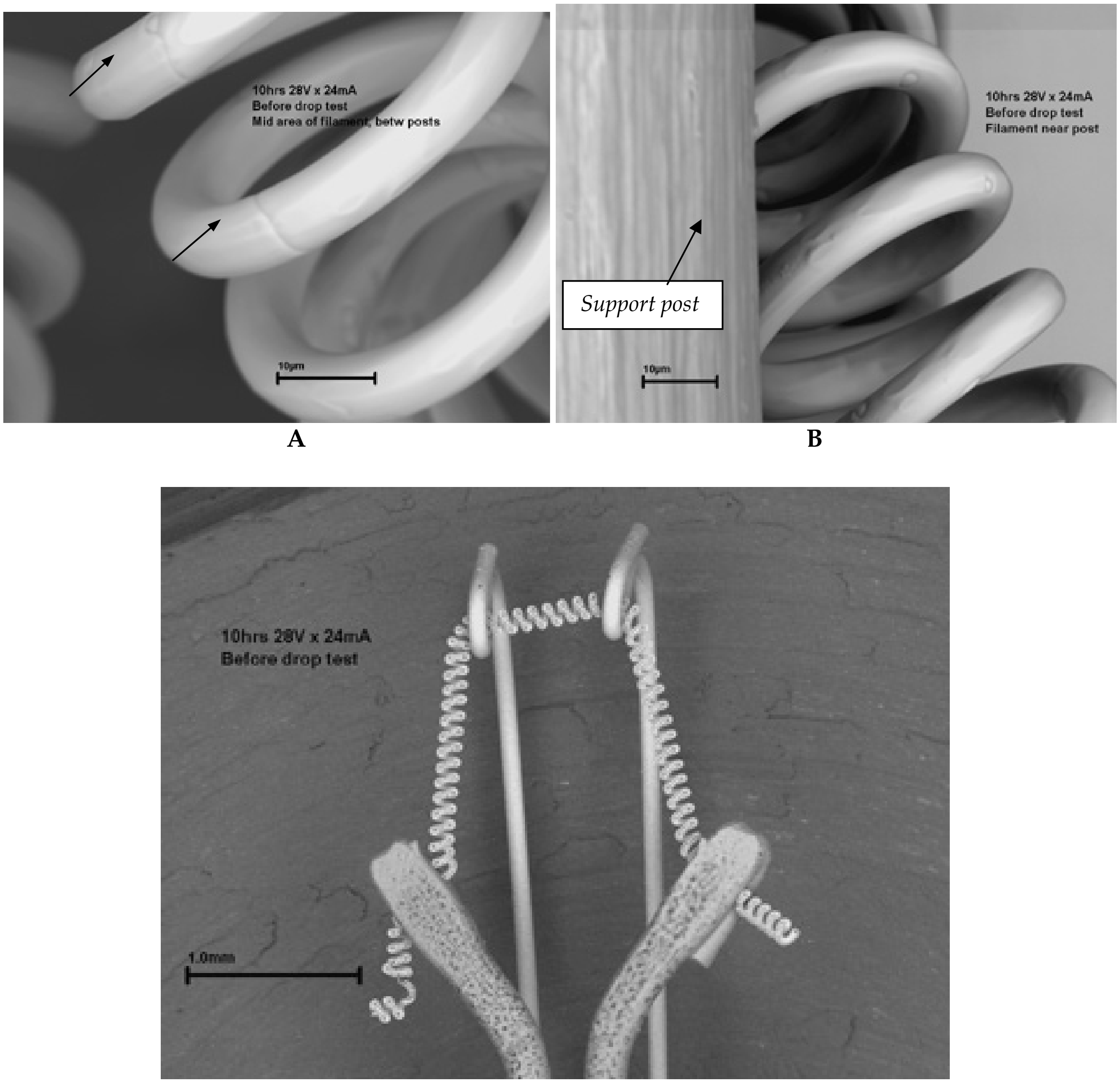
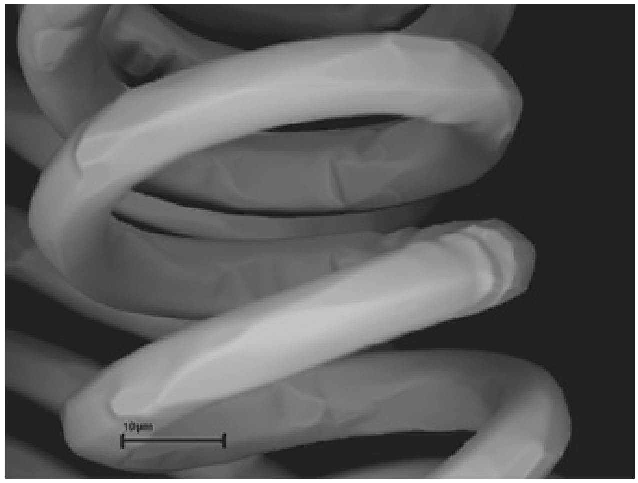
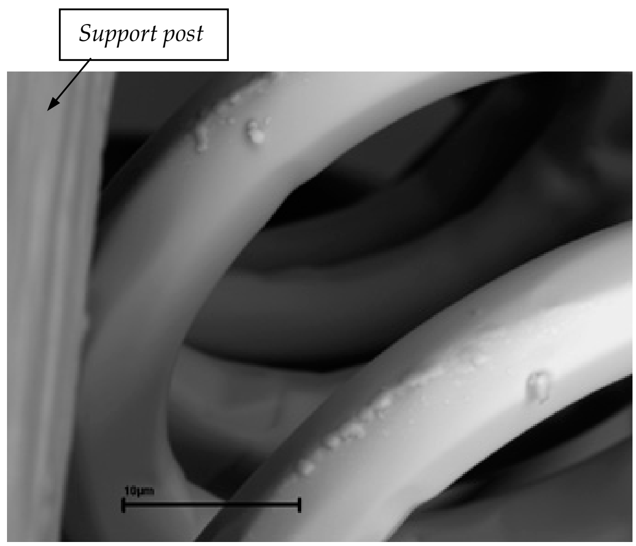


Figure 12 (A) Mid area of filament showing smooth surface and minor notching for a Type 2 lamp aged to 10 hours. (B) Near support post the filament exhibits similar damage for a Type 2 lamp aged to 10 hours. (C) No filament sag, typical appearance for Type 2 lamps aged up to and including 500hrs.

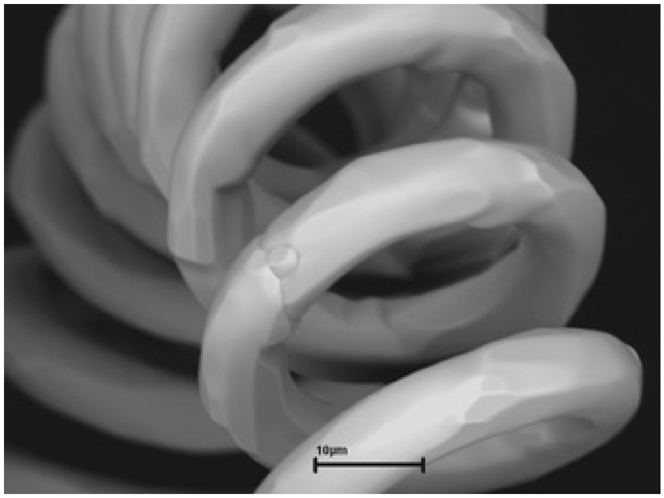


A

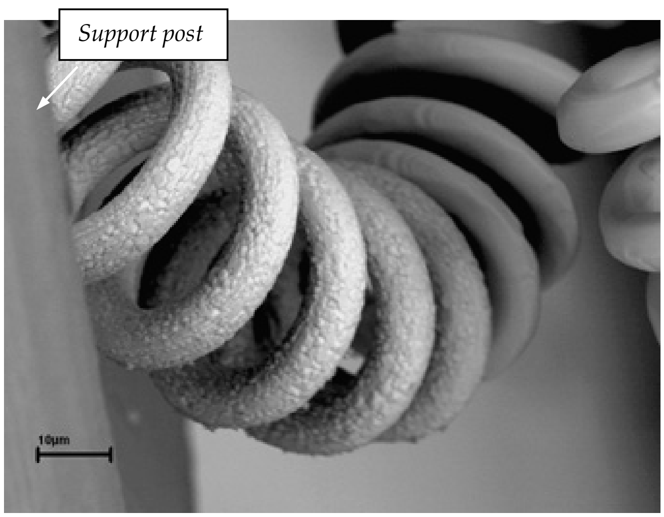


B

Figure 13 (A) Mid area of filament showing smooth surface to minor notching for a Type 2 lamp aged to 50 hours. (B) Near support posts the filament has a smooth surface with minor oxidation for a Type 2 lamp aged to 50 hours.

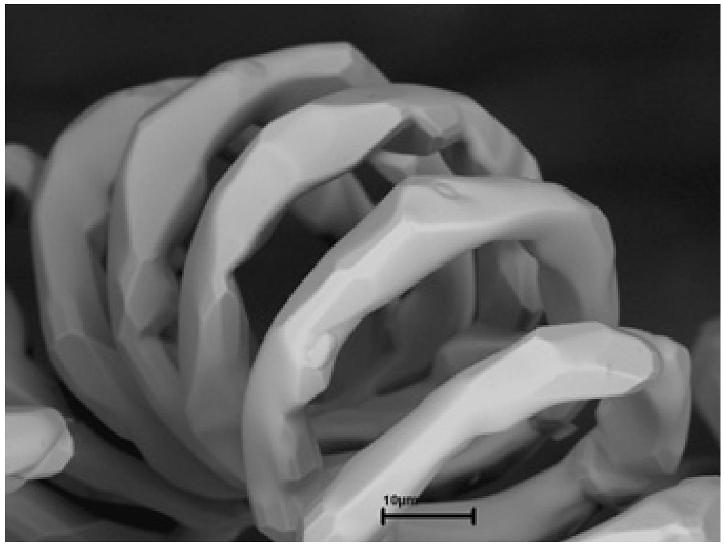


A

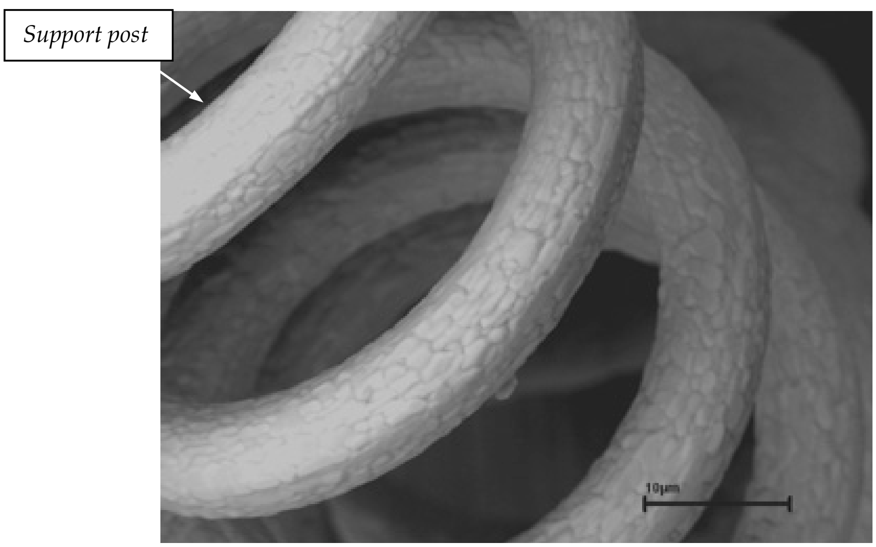


B

Figure 14 (A) Mid area of filament showing smooth surface to advanced notching for a Type 2 lamp aged to 100 hours. (B) Near support posts, scaled surface evident on filament of a Type 2 lamp aged to 100 hours.



A



B

Figure 15 (A) Mid area of filament showing smooth surface to severe notching for a Type 2 lamp aged to 500 hours. (B) Near support posts, scaled surface is evident for a Type 2 lamp aged to 500 hours.

4.3 Comparison of Lamp Types 1 & 2 after ageing

The behaviour of both lamp types throughout the ageing process was similar, except for minor differences such as:

- During the total ageing phase Type 2 lamps showed no visible sign of filament sag between the support posts when viewed at high magnification. Type 1 lamps have a distinctive sag, that commenced during the 10-hour ageing phase which increased at longer ageing times. (Refer to Table A-1 and Table A-2 for details.)
- After 10 hrs of ageing, Type 1 filaments had a scaled appearance whereas the Type 2 filaments had a smoother surface finish.
- After 100 hrs of ageing, Type 1 filaments exhibited scale converting to notching whereas Type 2 filaments displayed a smooth surface with indications of notching.
- Both lamp Types 1&2 aged to 500 hours, displayed heavy filament notching patterns between the support posts. It was observed that the surface was scaled where the filament makes contact with the support posts. At this area local temperatures are possibly reduced due to the heat sink effect caused by the support posts. See Figures 10b &15b for images.
- Between the two lamp types there was a variation between the filament diameters, Type 1 measured 10.5 μm whereas Type 2 measured 8.1 μm. This difference of 2.4 μm may have an influence on the life of the filament.

5. Drop Test Equipment

Drop tests were performed using a vertical rail impact-testing machine (Drop tower), located at DSTO Melbourne. The impact tester comprises a rail bearing fixed to a weighted block known as the 'impactor' that is raised to a known height and released. The 'impactor' slides up and down the rail freely, a manual device is provided to raise and release the 'impactor' at selected heights. The rail is fixed over a stable solid heavy metal anvil for the 'impactor' to strike.

For a test, the lamp support panel (Figure 16) is attached to the weighted 'impactor' block using high tensile socket head bolts The design of the lamp support panel is such that, only the weighted 'impactor' strikes the anvil (Figure 17), providing a controlled deceleration.

To determine the *g* values at impact, an accelerometer was mounted on to the lamp support panel via a threaded hole in its base. Placement of the accelerometer was towards the base of the lamp panel, on the rail bearing centreline and adjacent to the impact area. This position was in direct line and as close as possible to the impact area. No compensation allowance was made for energy absorption through the length of the panel. Impact *g* readings obtained for this test were considered to be a true indication of the impact, completely throughout the lamp support panel.

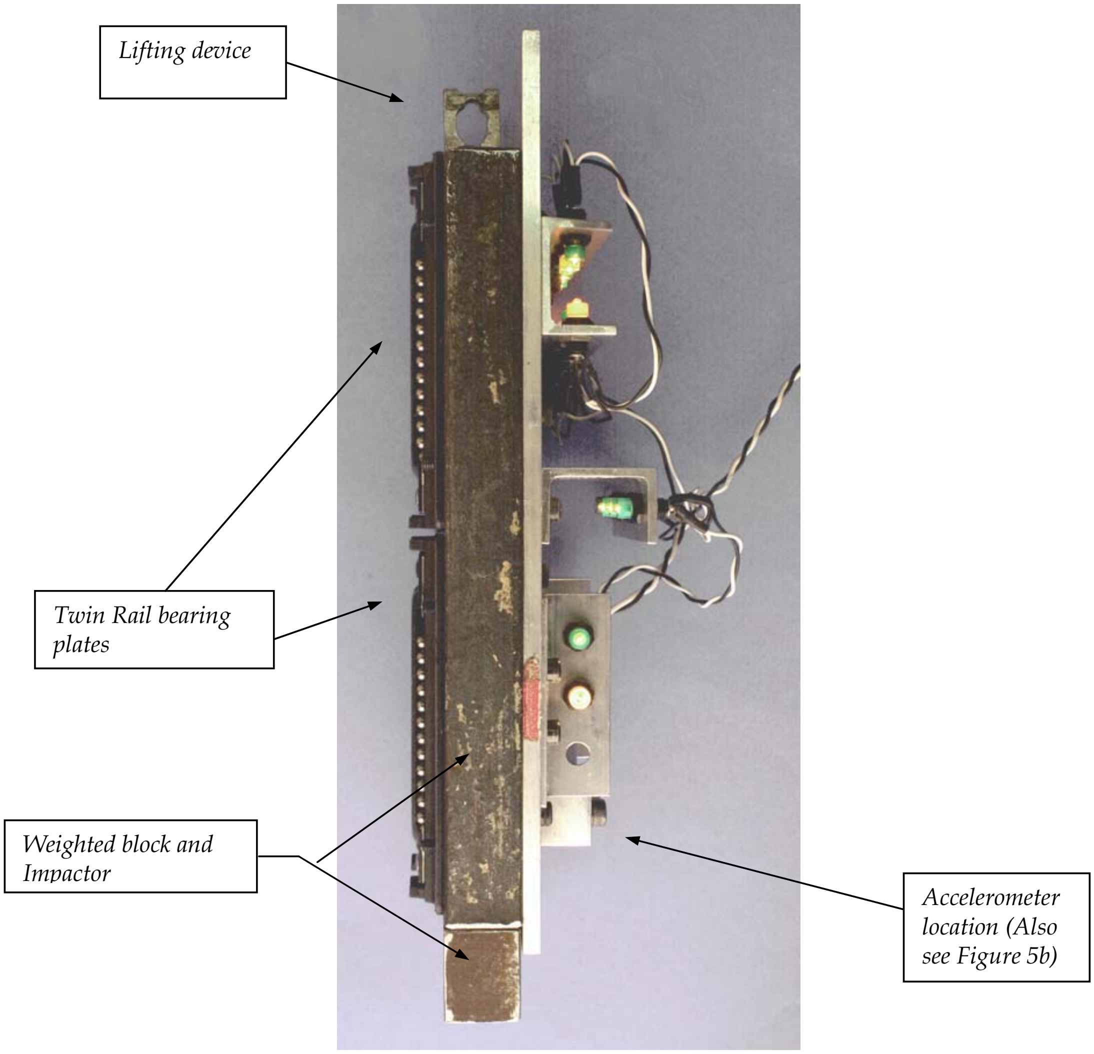


Figure 16   Typical Lamp panel with drop test attachment

Figure 17 DSTO Drop test tower with Lamp panel installed

5.1 Data Acquisition Equipment

Impact force readings were obtained from an OROS data acquisition software package linked with an OROS Dynamic Analyser and a Kistler Accelerometer. Specification for the accelerometer and settings of data acquisition are given below.

5.1.1 Accelerometer

Specifications:

• Manufacturer		Kistler
• Series	Piezotron low impedance	815A1
• Range		±5000 g
• Electrical Noise, independent of cable length		0.1 g rms
• Reference voltage sensitivity nom		1 mV/g
• Resonant Frequency		40±6 kHz
• Time Constant. Nom.		2 sec
• Low Frequency Response down nom. 5% at		0.2 Hz
• High Frequency Response up 5% ±2% at		6000 Hz
• Amplitude Linearity		1±%
• Transverse Sensitivity max.		5%
• Temperature Sensitivity Shift		0.025%/°F
• Vibration Limit	Axial	±7500 g
	Transverse	±500 g
• Shock Limit, 1ms pulse width		3000 g

5.1.2 Data acquisition setting parameters

- OROS Software version 4.41 revision 2.
- OROS FFT (Fast Fortran Transform) 10 channel analyser.
- Frequency range 0-20 kHz
- Windows set Rectangular 0% overlap
- FFT resolution 1601 lines (1 resolution line = 0.01953ms)
- No filtering.

6. Lamp Test Panel

To accommodate the lamps for impact testing two test panels were used, one for each lamp type, see Figure 5 for details. Each panel was designed to accommodate a maximum of 16 lamps in 4 different orientations. Using the vertical impact-testing machine these test panels (with lamps fitted) were installed then released from a nominal height to strike with a metal anvil. The lamps were then removed for a detailed filament examination.

6.1 Lamp Test Setup

Preliminary drop tests were performed on several spare lamps to establish suitable acceleration levels for the main series of tests. It was found that at an acceleration of 1000 g filament deformation became apparent and so 1000 *g* and 2500 *g* were chosen for the main tests. These values are in accordance with the results found elsewhere [2, 3].

The 160 lamps for each type were divided equally into two sets for "hot" testing and "cold" testing. Further division was made into five equal subsets of 16 which were aged to 0, 10, 50, 100 and 500 hours. This allowed for eight lamps for each drop test at the two acceleration levels.

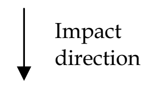
Lamps to undergo testing to 1000 *g* were marked with numbers from 1 to 8 and placed in similarly numbered positions on the drop test panel. Likewise lamps to undergo testing to 2500 *g* were numbered from 9 to 16 and placed in the corresponding positions on its test panel.

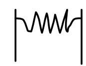
A diagram showing the layout of the lamps and the location of an accelerometer for the drop test panels is shown in Figure 18. Four of the lamps were aligned in the direction of the drop with two pointing upwards in and two pointing down. Four of the lamps were aligned perpendicular to the direction of the drop with two pointing the glass envelope towards the test panel and two pointing along the surface of the panel.

7. Orientation of the Lamps

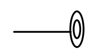
The layout of the lamps on the test panels were configured to hold the filaments in four different orientations to provide a representation of the lamps in an aircraft cockpit. See Figure 18 for details.

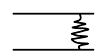
Filament relevant to impact direction



1). Support posts vertical and filament upright (Horizontal). 

2). Inverted 180° to position shown in 1 above. 

3). Support posts horizontal and filament horizontal. 

4). Support posts horizontal and filament vertical. 

For all drop tests there was no assurance that all lamps were placed in their exact positions as mentioned above. Alignment errors up to 45 degrees may occur due to the fact that it is difficult to hold the lamp in its correct position, sight the filament through opaque lamp covers and at the same time screw on the lamp cover to the holder.

8. Lamp Failure Modes

8.1 Types of Failure

Generally lamps fail in one of two ways not counting accidental breakage:

- Burnout, or
- Brittle breakage

With a voltage applied, a lamp filament is hot and ductile. Without a voltage applied the filament remains cold and is relatively brittle.

8.1.1 Impact Burnout Failure

The ageing process produces notches which render the filament thinner and weaker at some locations. The thinner sections have greater resistance than corresponding sections which result in local hot spots that are relatively softer. At impact the filament at a hot spot will undergo further stretching and thinning that exacerbates the local heating to the extent where melting and breaking may take place.

The ends at the location of a break are often tapered or necked with balls or beads of melted tungsten [5]. Severe notching from ageing can also produce localised heating and breaking in the absence of large accelerations. These typically break at one or both supporting posts and exhibit no stretching or deformation.

8.1.2 Brittle Failure

Brittle fracture occurs with sufficient acceleration of a cold filament. Notches that grow with ageing produce weakened sections that can result in filament breaks at lower accelerations. Brittle fracture occurs when the lamp is off and so there is no melting at the break. Occasionally movement of two free ends can cause them to touch, and if this takes place when power is applied, they can melt and fuse together to resume normal operation [5]. Another failure mode causes the filament to break in two locations so that a section becomes unattached and to move freely inside of the lamp. On rare occasions accelerations insufficient to break a filament can bend the support posts.

8.2 Filament deformation

Acceleration of hot filaments can result in deformation whereas a cold filament will remain unchanged in the absence of a break. Deformation is influenced by:

- the magnitude and acceleration,
- the spacing between posts,
- coil design, single or double helix,
- filament thinning through ageing.

8.2.1 Filament age sag

The degree of filament sag is related to ageing and is influenced by operating temperature, material structure, coil design and the effect of impurities. Age sag is usually downward and uniform. It can resemble sag produced by acceleration when incandescent.

8.2.2 Acceleration effects on hot filaments and lamps

A hot filament is relatively ductile giving rise to an increased propensity to stretch under acceleration compared to a cold filament. The resultant damage can be evidenced by increased coil spacing, stretching, sagging and possible entangling in a variety of configurations.

The existence of fused glass particles indicate that a lamp was operating when the glass bulb was broken. Ejected glass particles stopped by the hot filament may be fused and adhered to it. [5]

8.2.3 Acceleration effects on cold filaments and lamps

A filament that is cold when it experiences a large acceleration will exhibit no deformation in the absence of brittle fracture. A broken lamp bulb will not show any melting or fusing effects.

9. Impact testing results

The drop tests were carried out for both Type 1 and Type 2 lamps for conditions under which the lamps were operating, “hot” and not operating, “cold”. The tests were carried out for sets of lamps aged to 0, 10, 50, 100 and 500 hours before testing. The results for Type 1 Lamps are given in Tables 4 to 7. The results for Type 2 Lamps are shown in Tables 8 to 11.

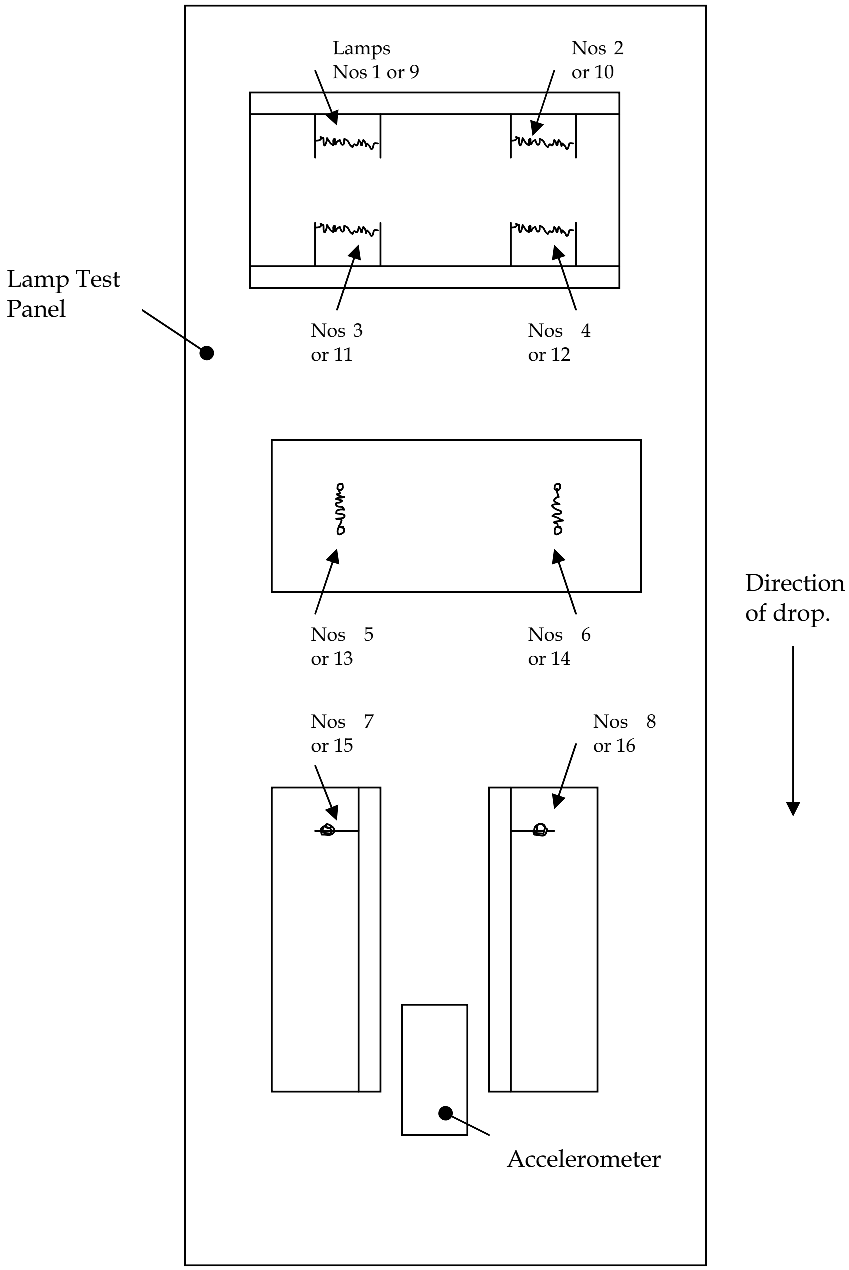


Figure 18 Front view of Test Panel showing lamp positions and orientation of the filaments

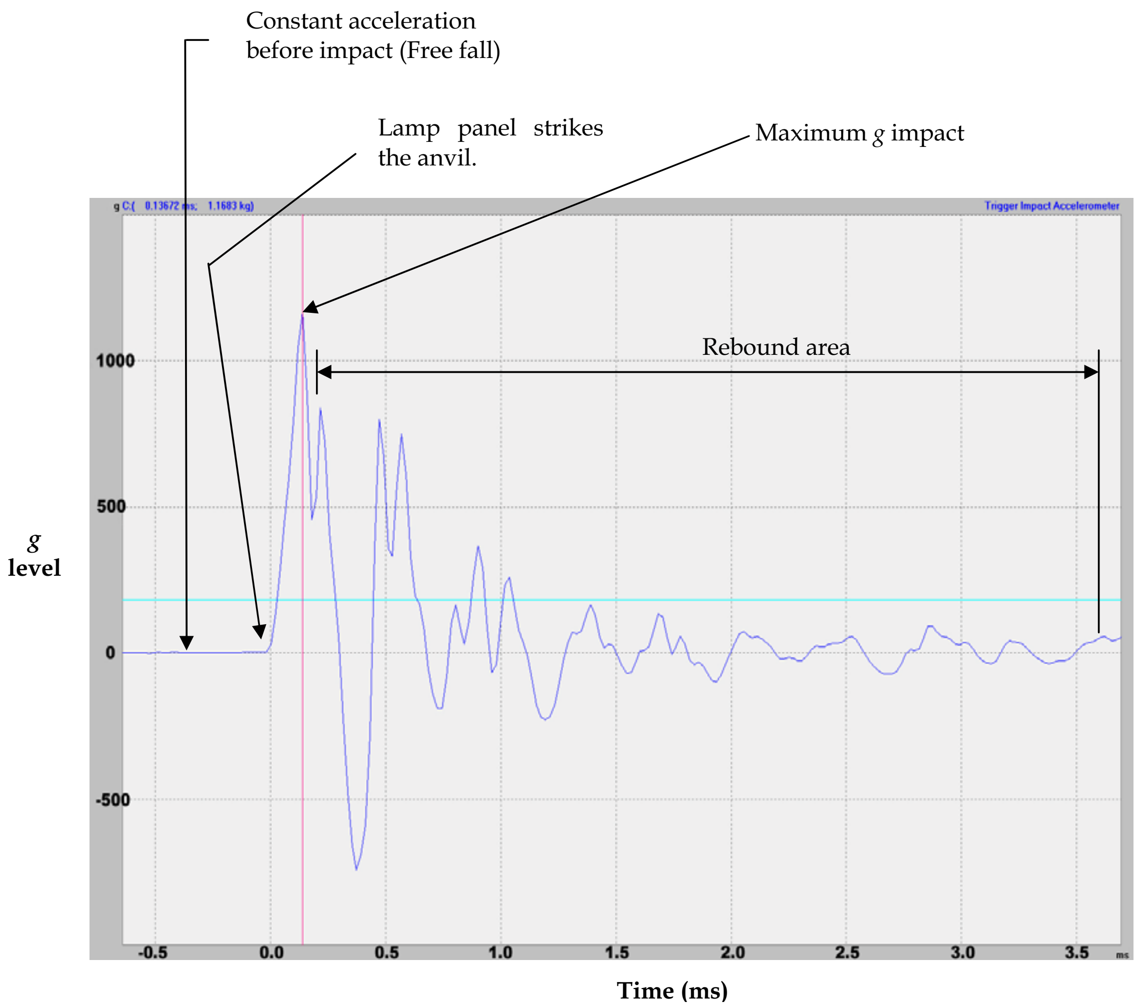


Figure 19   Typical accelerometer pulse trace

Table 4 Type 1 Lamps Cold @ 1000 g

Type 1 Lamps Cold 1000 *g*									
Aged hours	Filament break								Remarks
	Panel position No.								
	1	2	3	4	5	6	7	8	
0	no	no	no	no	no	no	no	no	All specimens except for No1 showed evidence of coil sagging.
10	no	no	no	no	no	no	no	no	All specimens no change from original shape.
50	no	no	no	no	no	no	no	no	All specimens no change from original shape.
100	no	no	no	no	no	no	no	no	All specimens no change from original shape.
500	no	no	no	yes	yes	no	yes	no	All specimens no change from original shapes except for Nos 4, 5 & 7 have filament fractures.

Table 5 Type 1 Lamps Hot @ 1000 g

Type 1 Lamps Hot 1000 *g*									
Aged hours	Filament break								Remarks
	Panel position No.								
	1	2	3	4	5	6	7	8	
0	no	no	no	no	no	no	no	no	Specimen Nos 2, 3, 4, 5, 6 & 8 showed evidence of deformation. Remainder no change.
10	no	no	no	no	no	no	no	no	All specimens no change from original shape.
50	no	no	no	no	no	no	no	no	Specimen Nos 5, 6, 7 & 8 evidence of slight deformation. Remainder no change.
100	no	no	no	no	no	no	no	no	Specimen Nos 1, 5, 6 & 7 displayed evidence of slight deformation. Also No 7 showed coil stretching. Remainder no change.
500	no	no	no Black	yes	no	no	no	no	All specimens no change from original shape, except for No 4 has a fractured filament. Also No 3 has a hint of black deposit on the glass.

Table 6 Type 1 Lamps Cold @ 2500 g

Type 1 Lamps Cold 2500 *g*									
Aged hours	Filament break Panel position No.								Remarks
	9	10	11	12	13	14	15	16	
0	yes	no	no	no	yes	no	no	no	All specimens displayed evidence of slight deformation; also Nos 9& 13 have filament fractures.
10	no	no	yes	no	yes*	yes	yes	no	Specimen Nos 9, 10, 12 & 16 no change from original shape. Nos 11, 14 & 15 have filament fractures. No 13* filament is undamaged but it has released itself from the fixing point on one contact post.
50	no	yes	no	no	no	no	yes	no	Specimen Nos 9 & 13 displayed evidence of coil stretching. Nos 11, 14 & 16 showed slight to major deformation. No 12, no change from its original shape. Nos 10 & 15 have filament fractures.
100	no	no	no	no	yes	no	no	no	Specimen Nos 9, 14& 15 showed evidence of deformation. Nos 10, 11, 12, & 16 displayed no change from the original profile. No 13 has a fractured filament.
500	yes	yes	yes	yes	yes	no	yes	no	All specimens have fractured filaments except for Nos. 14 & 16; they have not changed from the original profile.

Table 7 Type 1 Lamps Hot @ 2500 g

Type 1 Lamps Hot 2500 *g*									
Aged hours	Filament break Panel position No.								Remarks
	9	10	11	12	13	14	15	16	
0	no	no	no	no	no	no	no	no	Specimens Nos 9, 10, 11, 12 & 16 displayed slight evidence of deformation. Remainder showed major deformation.
10	no	no	no	no	no	no	no	no	All specimens showed major coil stretching, deformation, snaking and tangling, except for No 11 only a slight change in profile.
50	no	no	no	no	no	no	no	no	All specimens showed major coil stretching, deformation, snaking and tangling, except for No 10 only a slight change in profile.
100	no	no	no	no	no	no	yes	no	Specimen Nos 10, 11, 13, 14, 15 & 16 displayed evidence of major coil deformation, snaking and tangling also No 15 has fractured. Specimen Nos 9 & 12 has slight deformation.
500	no	no	no	no	no	no	no	no	All specimens displayed major evidence coil stretching, deformation, snaking and tangling

Table 8 Type 2 Lamps Cold @ 1000 g

Type 2 Lamps Cold 1000 *g*									
Aged hours	**Filament break**								**Remarks**
	Panel position No.								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
0	no	no	no	no	no	no	no	no	Specimen Nos 5, 6 & 8 slight evidence of coil stretching. Remainder no change.
10	no	no	no	no	no	no	no	no	All specimens no change from original shape.
50	no	no	no	no	no	no	no	no	All specimens no change from original shape.
100	no	no	no	no	no	no	no	no	All specimens no change from original shape.
500	no	yes	yes	no	no	no	no	no	All specimens no change from original shape except for Nos 2 & 3 have filament fractures.

Table 9 Type 2 Lamps Hot @ 1000 g

Type 2 Lamps Hot 1000 *g*									
Aged hours	**Filament break**								**Remarks**
	Panel position No.								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
0	no	no	no	no	no	no	no	no	All specimens displayed evidence of coil stretching; Nos 7 & 8 also displayed deformation.
10	no	no	no	no	no	no	no	no	All specimens displayed evidence of coil stretching; Nos 1, 7 & 8 also displayed deformation.
50	no	no	no	no	no	no	no	no	All specimens displayed evidence of coil stretching.
100	no	no	no	no	no	no	no	no	All specimens displayed evidence of coil stretching; also Nos 3, 5, 7 & 8 displayed deformation.
500	no	no	no	no	no	no	no	no	All specimens displayed evidence of coil stretching.

Table 10 Type 2 Cold Lamps @ 2500 g

Type 2 Lamps Cold 2500 *g*									
Aged hours	Filament break								Remarks
	Panel position No.								
	9	10	11	12	13	14	15	16	
0	no	no	no	no	no	no	no	no	Specimen No 11 slight evidence of coil stretching. Remainder no change.
10	no	no	no	no	no	no	no	no	Specimen Nos 11 & 15 slight evidence of coil stretching and deformation. Remainder no change.
50	no	no	no	no	no	no	yes	no	Specimen Nos 11 &16 evidence of coil stretching & No 15 has a filament fracture. Remainder no change.
100	no	no	no	yes	no	no	yes	no	Specimen No 16 evidence of coil stretching & Nos 12 & 15 have filament fractures. Remainder no change.
500	yes	yes	yes	yes	yes	no	yes	yes	Specimen No 14 slight evidence of coil stretching, remainder specimens have filament fractures.

Table 11 Type 2 Lamps Hot @ 2500 g

Type 2 Lamps Hot 2500 *g*									
Aged hours	Filament break								Remarks
	Panel position No.								
	9	10	11	12	13	14	15	16	
0	no	no	no	no	no	no	no	no	All specimens displayed evidence of major coil stretching and deformation.
10	no	no	no	no	no	no	no	no	All specimens displayed evidence of major coil stretching & deformation.
50	no	no	no	no	yes	no	no	yes	All specimens displayed evidence of major coil stretching & deformation. Nos 13 & 16 have filament fractures.
100	no	no	no	no	no	no	yes	no	All specimens displayed evidence of major coil stretching & deformation; also No 15 has a filament fracture.
500	no	no	no	no	no	yes	no	no	All specimens displayed evidence of major coil stretching & deformation; also No 14 has a filament fracture.

9.1 Type 1 cold filaments, profiles before & after impact.

The filament condition of lamps was examined under a high powered optical microscope to determine the relative damage effects of ageing and acceleration. Images of some samples provided in the following sections illustrate ageing and impact effects by showing the condition of lamps tested with cold filaments before and after acceleration tests of 1000 *g* and 2500 *g*.

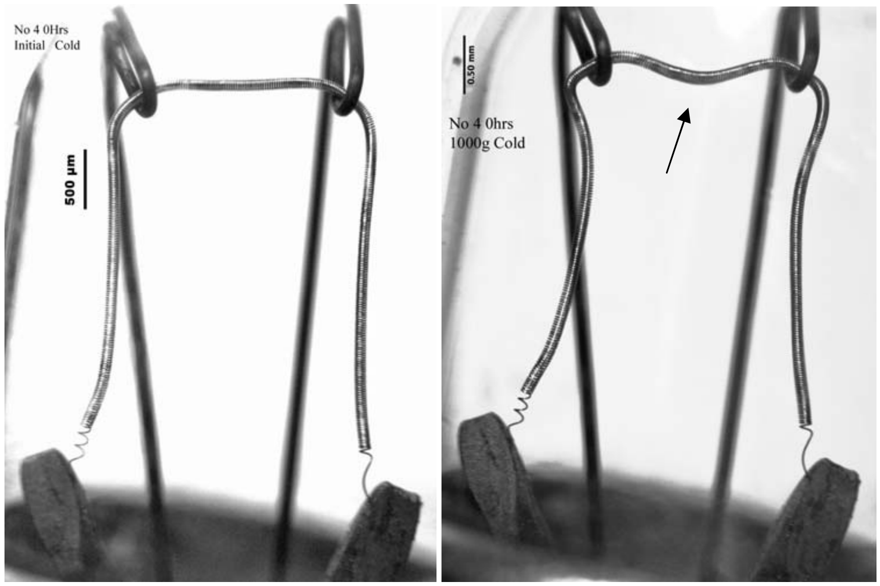
9.1.1 1000 *g* Cold impact profiles.

Images in Figures 20 to 22 & B1 show the state of filaments before and after acceleration at 1000 *g* for cold filaments of Type 1 lamps aged to 0, 10 and 500 hours. Before testing there was evidence of ongoing stretching as ageing was increased. Drop testing for each level of ageing slightly increased stretching and introduced a small amount of displacement to the filament so that a slight deformation could be discerned. The stretching due to ageing is more prominent than that from drop testing.

A

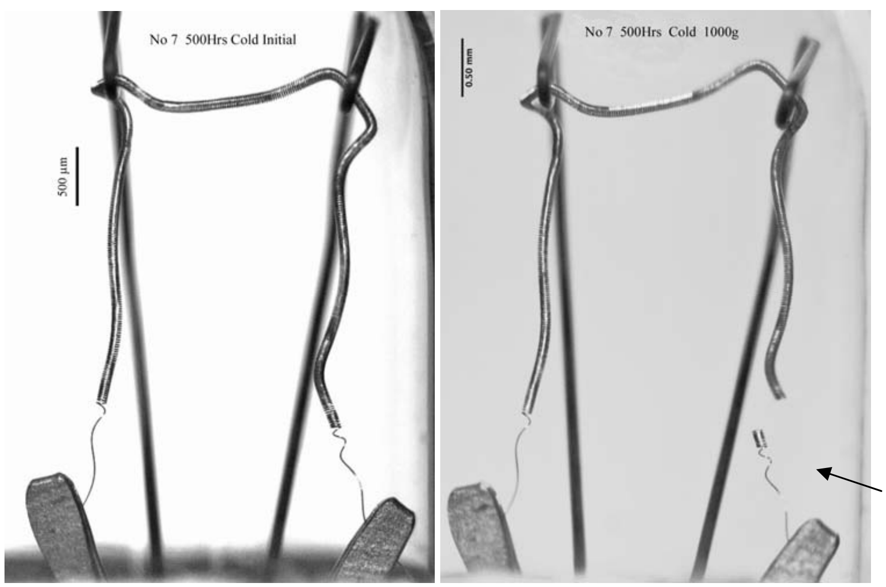
B

Figure 20 (A) The image on the left shows Type 1 lamp No. 3 after 10 hours of ageing. (B) The image on the right shows the same lamp after acceleration while cold of 1000 g with no change in the original profile of the filament.



A **B**

Figure 21 (A) The image on the left shows Type 1 lamp No. 4 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 1000 g while cold with a resultant sag in the filament profile.



A **B**

Figure 22 (A) The image on the left shows Type 1 lamp No. 7 after 500 hours of ageing and exhibiting filament sag. (B) The image on the right shows the same lamp after an acceleration of 1000 g while cold with no further evidence of sagging. The filament has however fractured.

A summary of all Type 1 lamps tested at 1000 *g* with cold filaments is given in Table 12 after reference to all relevant images and Table 4. The effect of drop testing can be seen to introduce a relatively small amount of deformation. For lamps with zero ageing, the filaments initially had virtually no sag and hence the slight deformation produced by acceleration was clearly discernable in seven lamps. Filaments that had been aged showed similar deformation. Ageing to 500 hours introduced an increased incidence of filament fracture.

Table 12 Type 1 Cold lamp defects @ 1000 g

Aged hours	Defect Description			
	Maintained original profile	Slight deformation (Stretching & sagging)	Deformation (Snaking & tangling)	Fracture
0	1	7	0	0
10	8	0	0	0
50	8	0	0	0
100	8	0	0	0
500	5	0	0	3

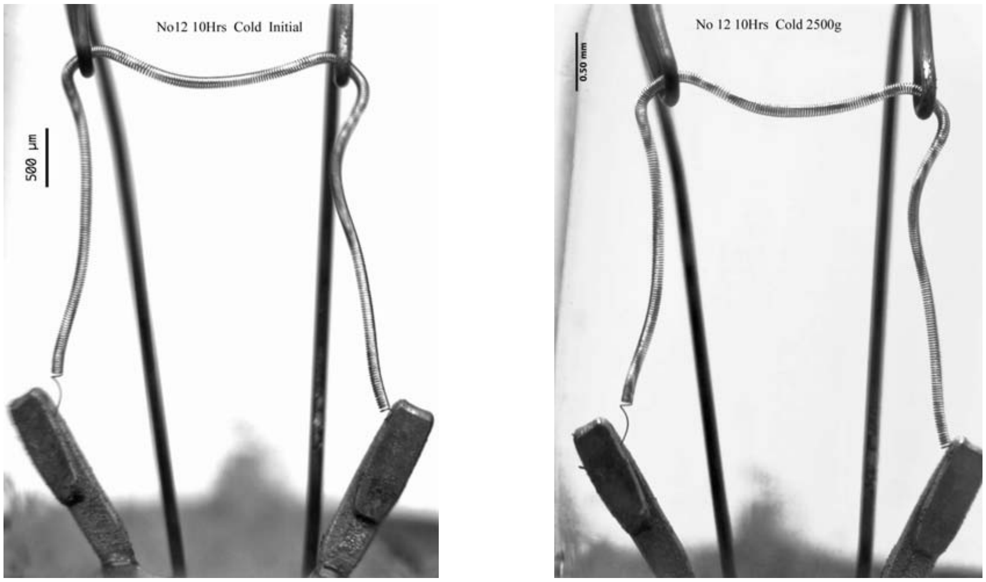
9.1.2 2500 *g* Cold impact profiles.

Images in Figures 23 to 25 & B-2 show the state of filaments before and after acceleration at 2500 *g* for cold filaments of Type 1 lamps aged to 0, 10, 50 and 500 hours. Drop testing for each level of ageing slightly increased stretching that was not recognisably different to that found for accelerations of 1000 *g*.

A

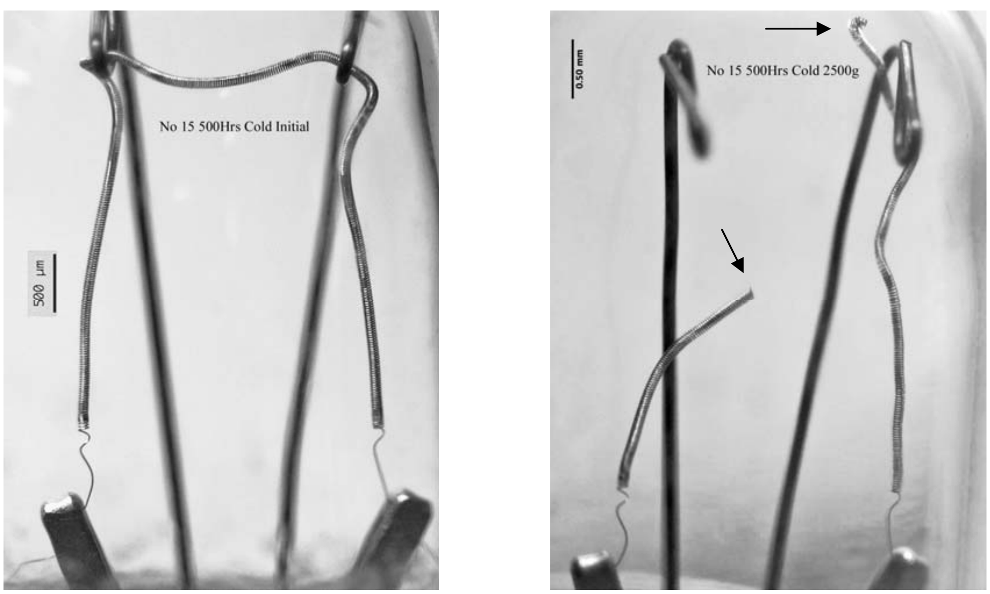
B

Figure 23 (A) The image on the left shows Type 1 lamp No. 14 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 2500 g while cold and showing slight coil sag and deformation.



A **B**

Figure 24 (A) The image on the left shows Type 1 lamp No. 12 aged to 10 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while cold with no evidence of a change in profile. This is typical of tests on similar lamps aged to 10, 50, 100 and 500 hours.



A **B**

Figure 25 (A) The image on the left shows Type 1 lamp No. 15 aged to 500 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while cold with a resultant filament fracture which was typical for several lamps.

A summary of all Type 1 lamps tested at 2500 *g* with cold filaments is given in Table 13 after reference to all relevant images and Table 6. As for similar tests at 1000 *g* slight discernable deformations were produced by acceleration for lamps with zero ageing. Slight deformations were also discernable at 50 hours and 100 hours ageing. At accelerations of 2500 *g* there was an increased incidence of filament fractures compared to 1000 *g* accelerations.

Table 13 Type 1 Cold lamp defects @ 2500 g

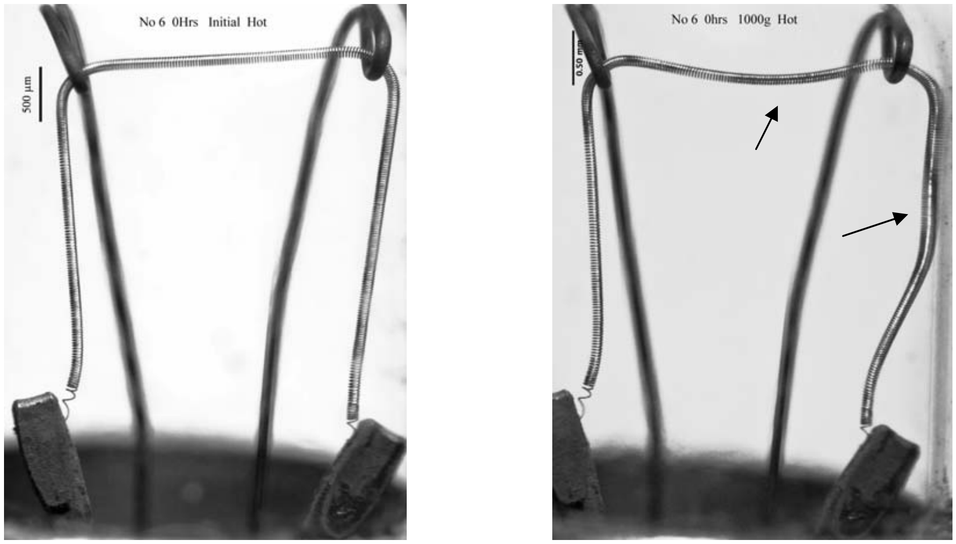
Aged hours	**Defect Description**			
	Maintained original profile	**Slight deformation (Stretching & sagging)**	**Deformation (Snaking & tangling)**	**Fracture**
0	0	6	0	2
10	4	0	0	4
50	1	5	0	2
100	4	3	0	1
500	2	0	0	6

9.2 Type 1 hot filaments, profiles before & after impact

After acceleration tests of 1000 *g* and 2500 *g* tests, the images of Type 1 lamps with hot filaments were examined under a high powered optical microscope and evaluated. Images of some samples provided in the following sections illustrate the deformation and fracture characteristics.

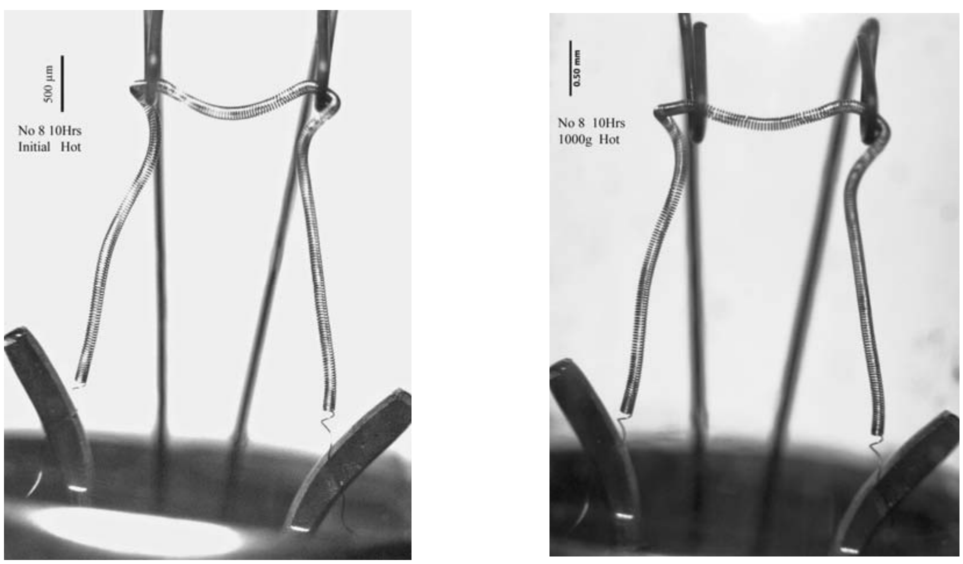
9.2.1 1000 *g* hot impact profiles

Images in Figures 26 to 28 & B3 show the state of filaments before and after acceleration of 1000 *g* for hot filaments of Type 1 lamps aged to 0, 10 and 100 hours. Before testing there was evidence of ongoing stretching as ageing was increased and some further stretching is sometimes evident with acceleration tests.



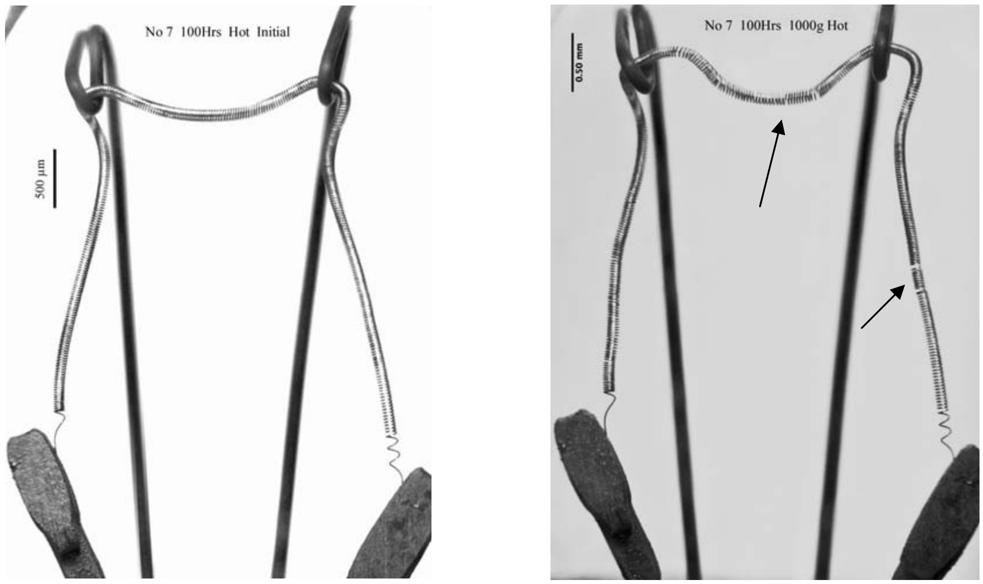
A **B**

Figure 26 (A) The image on the left shows Type 1 lamp No. 6 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 1000 g while hot with significant filament sag and deformation which is typical also of several lamps aged to 0, 50 and 100 hours.



A **B**

Figure 27 (A) The image on the left shows Type 1 lamp No. 8 aged to 10 hours and which has some sagging. (B) The image on the right shows the same lamp after an acceleration of 1000 g while hot and shows no evidence of further sagging. This is typical of most lamps after acceleration of 1000 g while hot.



A B

Figure 28 (A) The image on the left shows Type 1 lamp No. 7 aged to 100 hours. (B) The image on the right shows the same lamp after an acceleration of 1000 g while hot with coil stretch and sag. Coil stretch was evident on this lamp only. The deformation is typical of that shown by several lamps aged to 0, 50 and 100 hours.

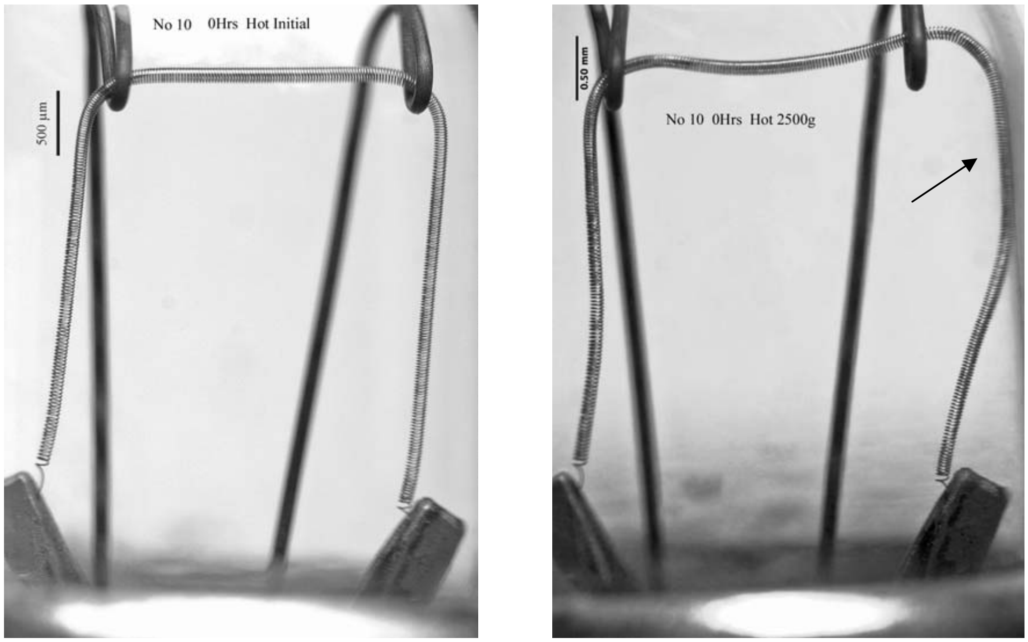
A summary of all Type 1 lamps tested at 1000 *g* with hot filaments is given in Table 14 after reference to all relevant images and Table 5. Most of the filaments maintained their original shape, although evidence of slight coil sagging did occur in several lamps from the age groups 0, 50 & 100. Only one filament fracture occurred from the 500 hr group. Also from the same group, a lamp appeared with a blackened glass envelope which still functioned correctly after impact.

Table 14 Type 1 Hot lamp defects @ 1000 g

Aged hours	Defect Description			
	Maintained original profile	Slight deformation (Stretching & sagging)	Deformation (Snaking & tangling)	Fracture
0	2	6	0	0
10	8	0	0	0
50	2	4	0	0
100	3	5	0	0
500	7	0	0	1

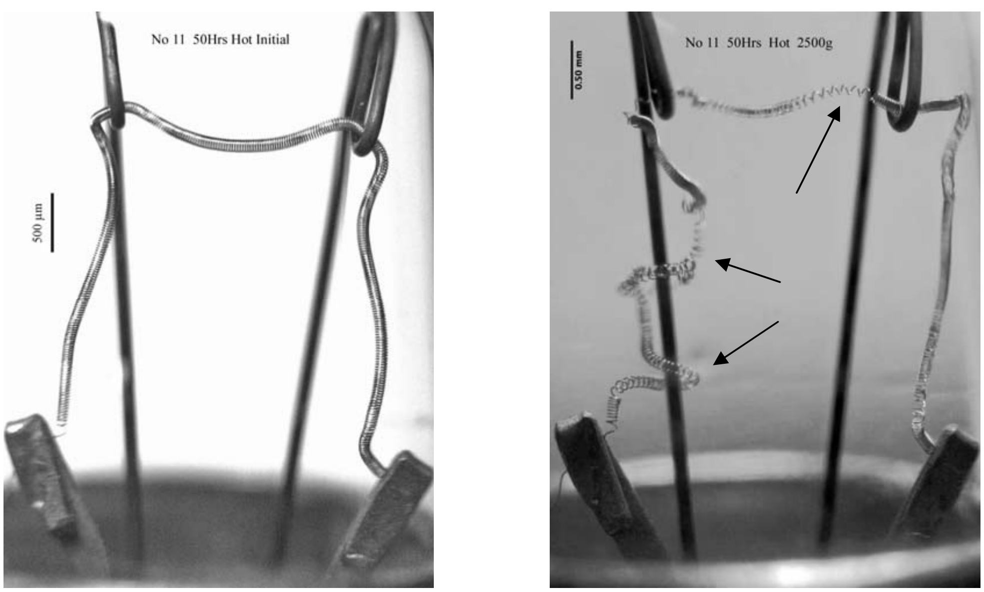
9.2.2 2500 *g* Hot impact profiles

Images in Figures 29 to 31 & B-4 show the state of filaments of Type 1 lamps before and after acceleration at 2500 *g* for hot filaments aged to 0, 100 and 500 hours. Before testing there was evidence of ongoing stretching as ageing was increased. Drop testing for each level of ageing produced filament deformation in all lamps and also one filament fracture.



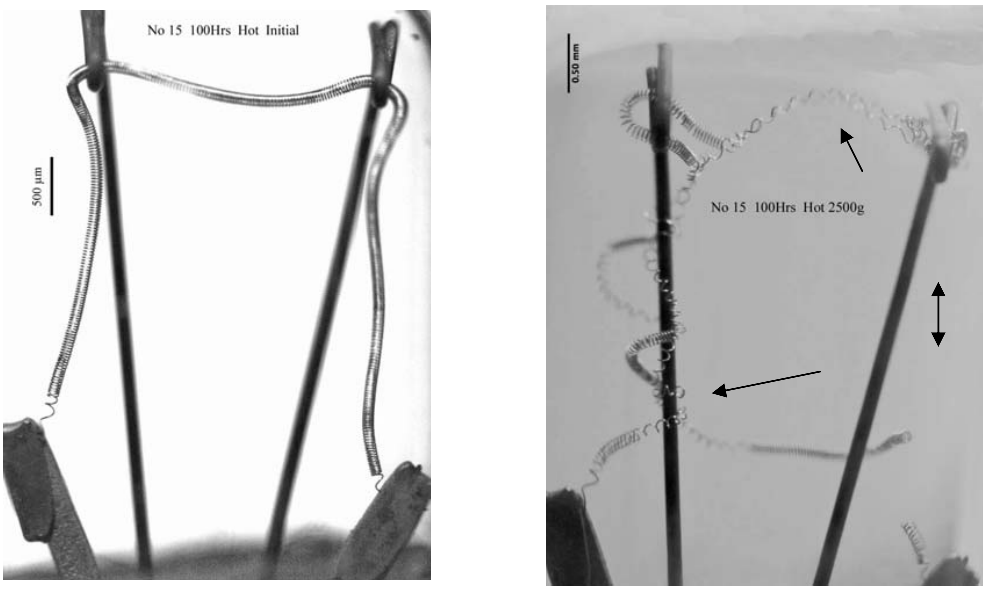
A **B**

Figure 29 (A) The image on the left shows Type 1 lamp No. 10 without ageing. (B) The image on the right shows the same lamp after an acceleration of 2500 g while hot showing slight deformation. The deformation is typical of that shown in several lamps aged to 0, 50 and 100 hours.



A **B**

Figure 30 *(A) The image on the left shows Type 1 lamp No. 11 aged to 50 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while hot with major coil deformation including snaking, tangling and stretching. This is typical damage for most lamps tested to the same conditions.*



A **B**

Figure 31 *(A) The image on the left shows Type 1 lamp No. 15 aged to 100 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while hot with major coil deformation including snaking, tangling, stretching and fracture. This is typical for lamps tested to the same conditions.*

A summary of all Type 1 lamps tested at 2500 *g* with hot filaments is given in Table 15 after reference to all relevant images and Table 7. Most lamps at this impact level have displayed filament snaking and tangling except for the 0 hour aged group, which showed slight deformation for the majority. Furthermore, only one filament fracture occurred.

Table 15 *Type 1 Hot lamp defects @ 2500 g*

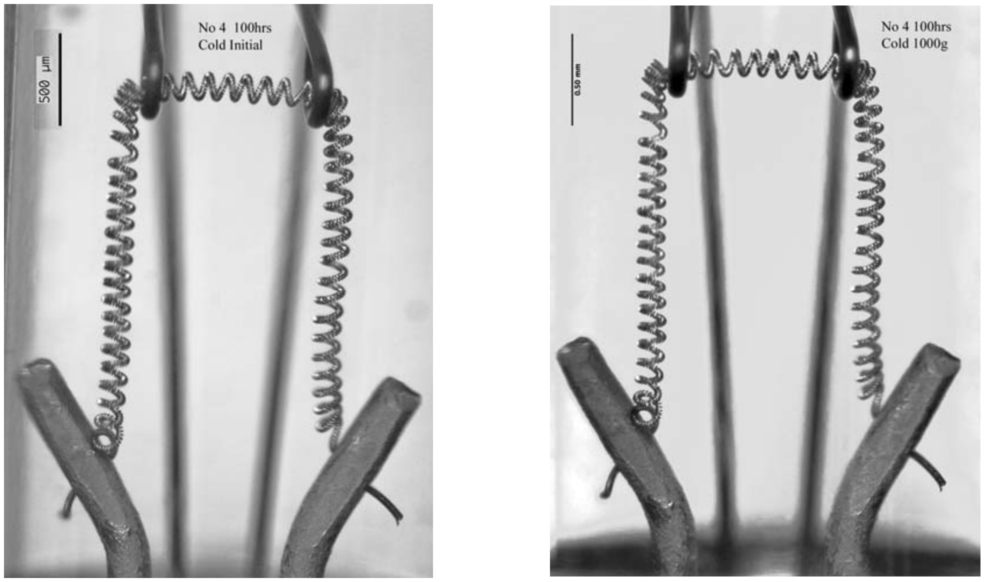
Aged hours	**Defect Description**			
	Maintained original profile	**Slight deformation (Stretching & sagging)**	**Deformation (Snaking & tangling)**	**Fracture**
0	0	5	3	0
10	0	1	7	0
50	0	1	7	0
100	0	2	5	1
500	0	0	8	0

9.3 Type 2 cold filaments, profiles before & after impact

The images of Type 2 lamps with cold filaments were examined under the microscope and evaluated before and after acceleration of 1000 *g* and 2500 *g*. Images of some samples provided in the following sections illustrate the deformation and fracture characteristics.

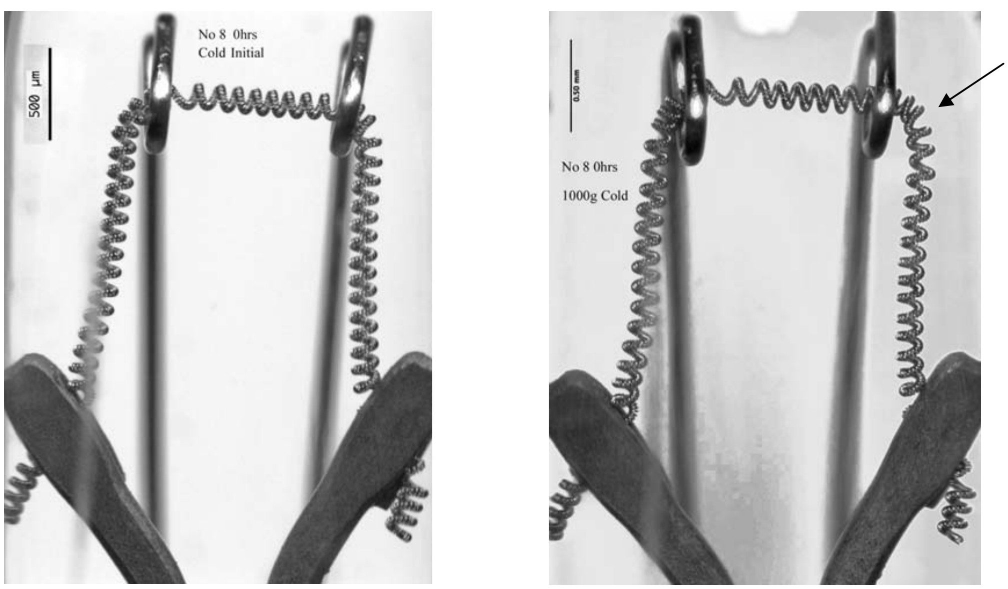
9.3.1 1000 *g* Cold impact profiles.

Images in Figures 32 to 34 & C-1 show the state of filaments of Type 2 lamps before and after acceleration at 1000 *g* for cold filaments aged to 0, 100 and 500 hours. Before testing there was little evidence of filament stretching until the ageing reached 500 hours. The filament for Type 2 lamps exhibited little stretching.



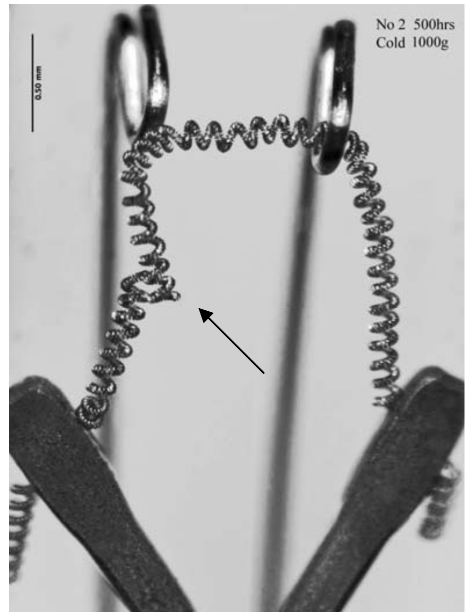
A **B**

Figure 32 (A) The image on the left shows Type 2 lamp No. 4 aged to 100 hours. (B) The image on the right shows the same lamp after an acceleration of 1000 g while cold. There is no sign of damage or filament sagging before or after acceleration.



A **B**

Figure 33 (A) The image on the left shows Type 2 lamp No. 8 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 1000 g while cold resulting in slight stretching. The type of damage occurred in two other lamps tested to the same condition.



A **B**

Figure 34 (A) The image on the left shows Type 2 lamp No. 2 aged to 500 hours. (B) The image on the right shows the same lamp after an acceleration of 1000 g while cold with a resultant filament fracture which occurred in two lamps of this group.

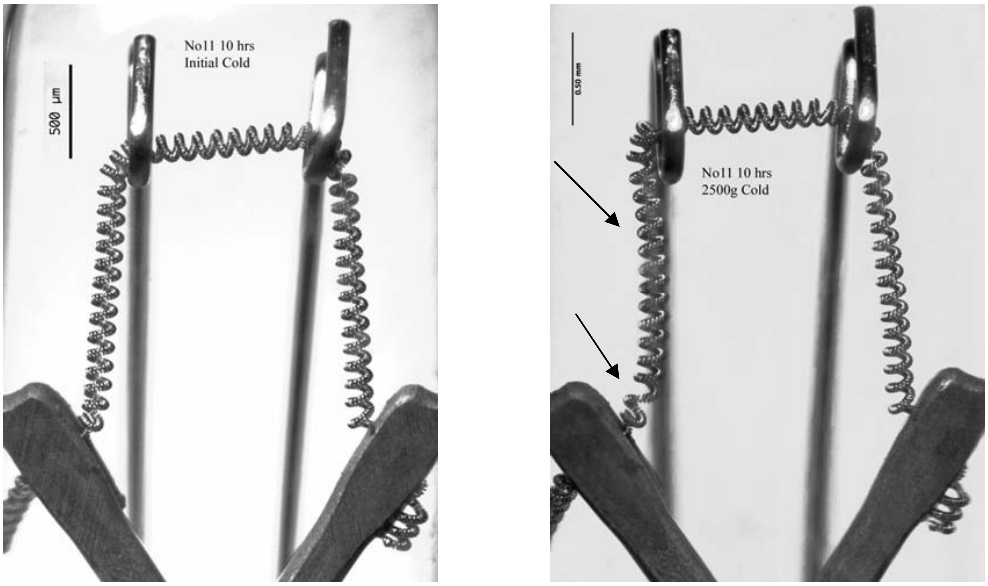
A summary of all Type 2 lamps tested at 1000 *g* with cold filaments is given in Table 16 after reference to all relevant images and Table 8. There is virtually no deformation evident from the tests. However, 3 lamps from the 0 hours age group did show a small amount of filament stretch. In addition 2 filament fractures were present in the 500 hour group.

Table 16 Type 2 Cold lamp defects @ 1000 g

Aged hours	Defect Description			
	Maintained original profile	Slight deformation (Stretching & sagging)	Deformation (Snaking & tangling)	Fracture
0	5	3	0	0
10	8	0	0	0
50	8	0	0	0
100	8	0	0	0
500	6	0	0	2

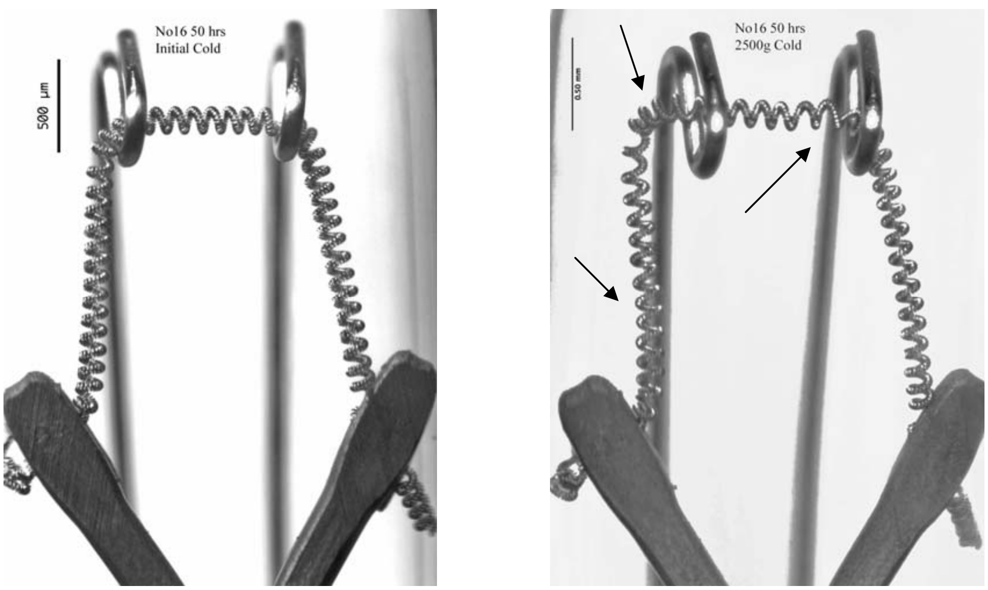
9.3.2 2500 *g* Cold impact profiles.

Images in Figures 35 to 37 & C-2 show the state of filaments of Type 2 lamps before and after acceleration at 2500 *g* for cold filaments aged to 10, 50 and 500 hours. Before testing there was little evidence of filament stretching. The filament for Type 2 lamps exhibited little stretching.



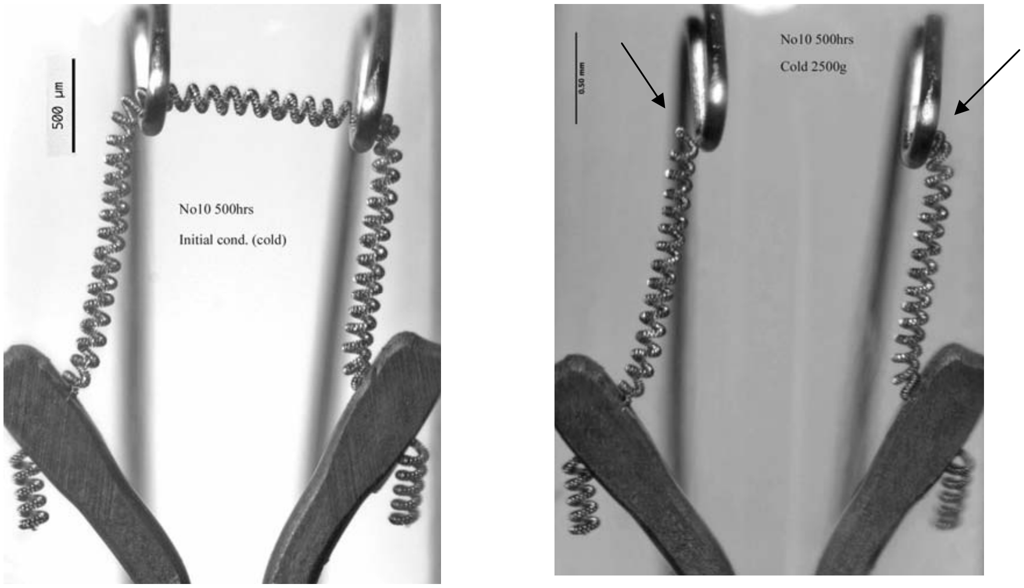
A **B**

Figure 35 (A) The image on the left shows Type 2 lamp No. 11 aged to 10 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while cold with resultant slight filament deformation. This type of damage is typical to that found in all groups of type 2 lamps.



A **B**

Figure 36 (A) The image on the left shows Type 2 lamp No. 14 aged to 50 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while cold with resultant coil stretch and deformation. The type of damage was found in several Type 2 lamps from all groups when accelerated to 2500 g when cold.



A B

Figure 37 (A) The image on the left shows Type 2 lamp No. 10 aged to 500 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while cold with resultant filament fracture. Several Type 2 lamps aged to 50, 100 & 500 hours produce filament fractures after being accelerated to this level while cold.

A summary of all Type 2 lamps tested at 2500 *g* with cold filaments is given in Table 17 after reference to all relevant images and Table 10. The majority of the filaments maintained their original shape; however minor coil stretching did occur in all groups. A large number of filament fractures appeared in the 500 hr group with 7 failures. For the other groups 1 fracture occurred with a lamp aged to 50 hours and 2 fractures occurred for lamps aged to 100 hours.

Table 17 Type 2 Cold lamp defects @ 2500 g

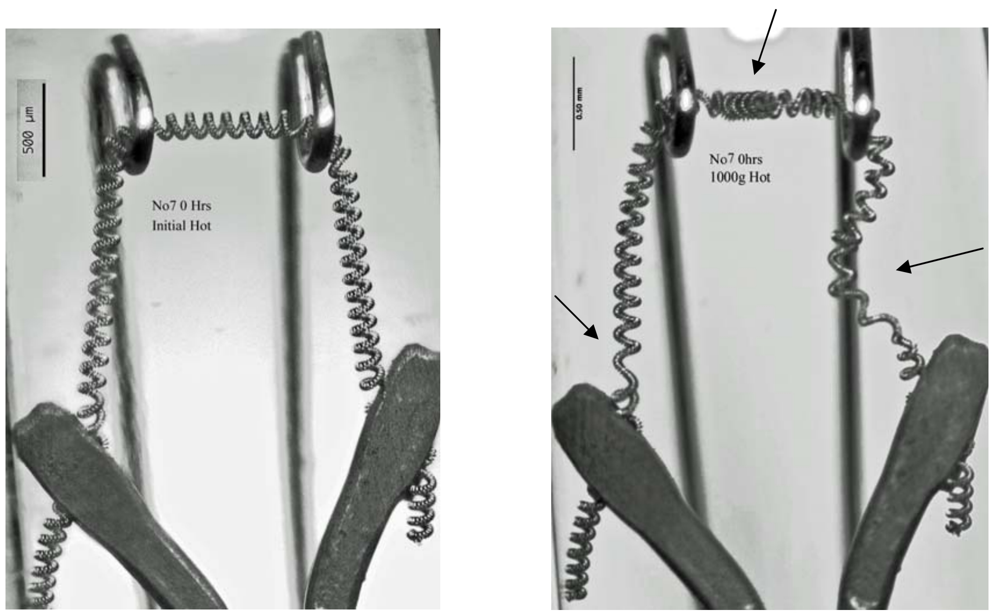
Aged hours	**Defect Description**			
	Maintained original profile	**Slight deformation (Stretching & sagging)**	**Deformation (Snaking & tangling)**	**Fracture**
0	7	1	0	0
10	6	2	0	0
50	3	2	0	1
100	5	1	0	2
500	0	1	0	7

9.4 Type 2 hot filaments, images before & after impact

After acceleration tests of 1000 *g* and 2500 *g* tests, the images of Type 2 lamps with hot filaments were examined under the microscope and evaluated. Images of some samples provided in the following sections illustrate the deformation and fracture characteristics.

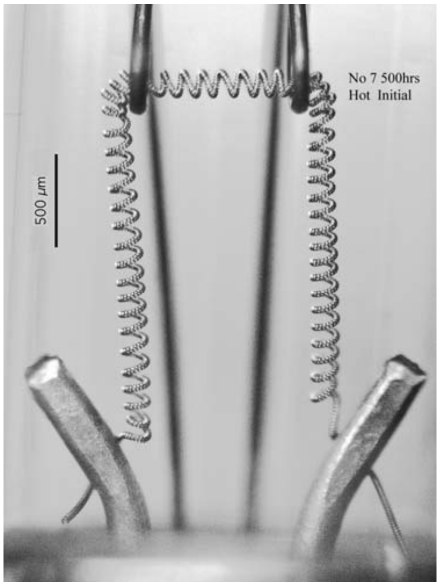
9.4.1 1000 *g* Hot impact profiles

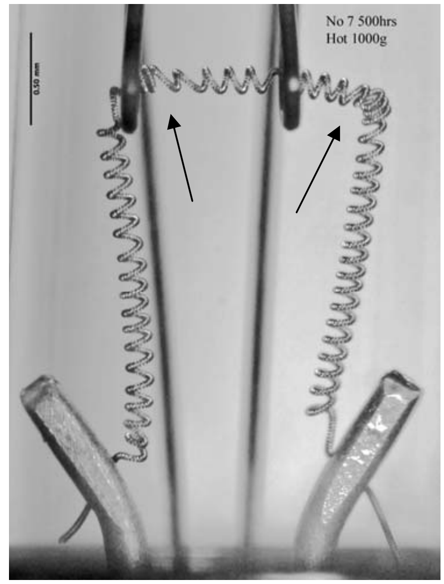
Images in Figures 38, 39 & C-3 show the state of filaments of Type 2 lamps before and after acceleration at 1000 *g* for hot filaments aged to 0 and 500 hours. Before testing there was little evidence of filament stretching. The hot filaments for Type 2 lamps exhibited stretching for all observations after testing.



A **B**

Figure 38 (A) The image on the left shows Type 2 lamp No. 7 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 1000 g while hot producing coil stretch and deformation. The deformation is typical of that produced by several Type 2 lamps when accelerated hot at 1000 g.





A **B**

Figure 39 (A) The image on the left shows Type 2 lamp No. 7 aged to 500 hours. (B) The image on the right shows the same lamp after an acceleration of 1000 g while hot producing coil stretch which was typical in most lamps accelerated to 1000 g while hot.

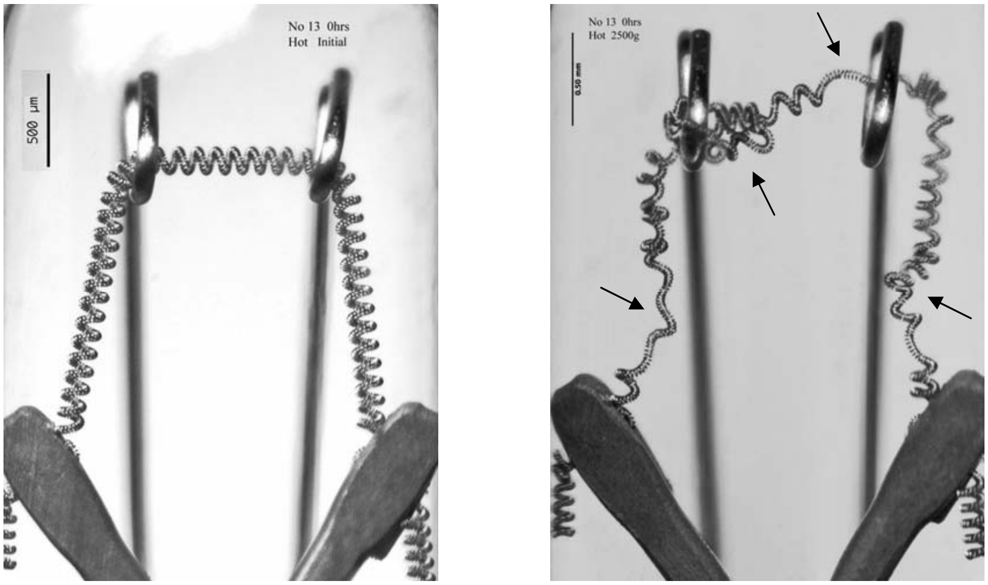
A summary of all Type 2 lamps tested at 1000 *g* with hot filaments is given in Table 18 after reference to all relevant images and Table 9. It was found that all lamps have similar conditions of slight coil deformation including stretching. No filament fractures were observed.

Table 18 Type 2 Hot lamp defects @ 1000 g

Aged hours	**Defect Description**			
	Maintained original profile	**Slight deformation (Stretching & sagging)**	**Deformation (Snaking & tangling)**	**Fracture**
0	0	8		0
10	0	8		0
50	0	8	0	0
100	0	8		0
500	0	8	0	0

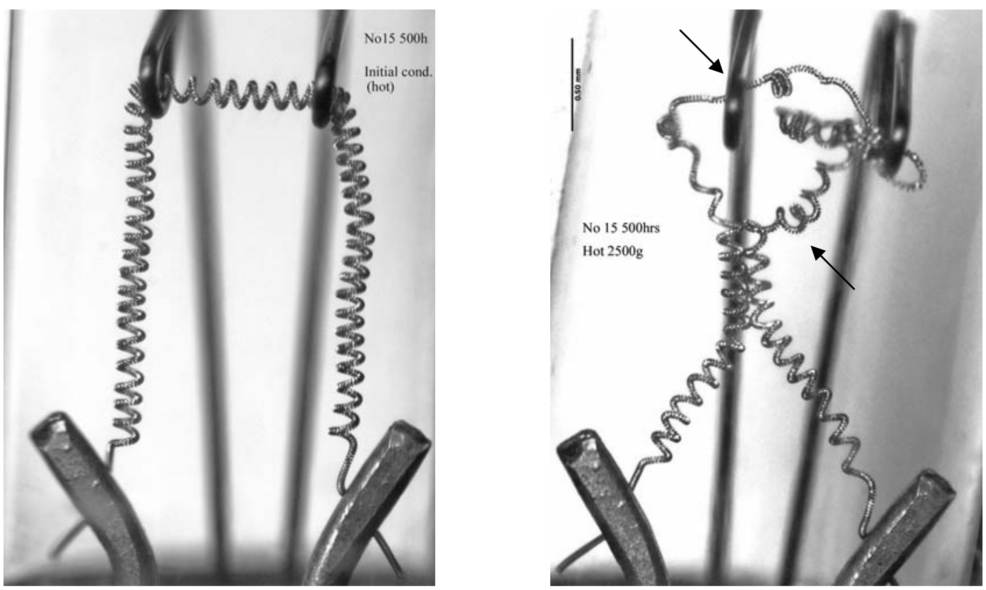
9.4.2 2500 *g* Hot impact profiles.

Images in Figures 40 to 41 & C-4 show the state of filaments of Type 2 lamps before and after acceleration at 2500 *g* for hot filaments aged to 0, 50 and 500 hours. Before testing there was little evidence of filament stretching. The hot filaments for Type 2 lamps exhibited significant deformation for all observations after testing.



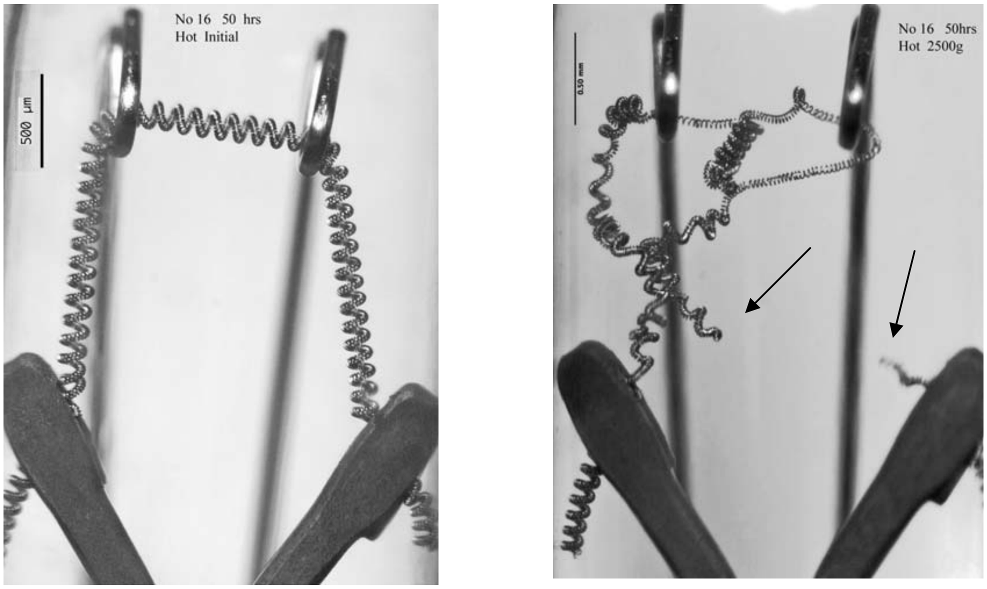
A **B**

Figure 40 (A) The image on the left shows Type 2 lamp No. 13 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 2500 g while hot with resultant major coil deformation including snaking, tangling and stretching. The damage is typical of that produced by 2500 g acceleration of hot Type 2 lamps.



A **B**

Figure 41 (A) The image on the left shows Type 2 lamp No. 15 with no ageing. (B) The image on the right shows the same lamp after an acceleration of 2500 g while hot with resultant coil deformation including snaking, tangling and stretching.



A **B**

Figure 42 (A) The image on the left shows Type 2 lamp No. 16 aged to 50 hours. (B) The image on the right shows the same lamp after an acceleration of 2500 g while hot with resultant coil deformation including snaking, tangling, stretching and fracture. Filament fracture occurred for several Type 2 lamps aged to 50, 100 and 500 hours when accelerated to 2500 g while hot.

A summary of all Type 2 lamps tested at 2500 *g* with hot filaments is given in Table 19 after reference to all relevant images and Table 11. At this impact level most lamps have displayed major filament deformation with snaking and tangling. Overall 4 filament fractures occurred with 2 for lamps aged to 50 hours and 1 each for lamps aged to 100 hours and 500 hours.

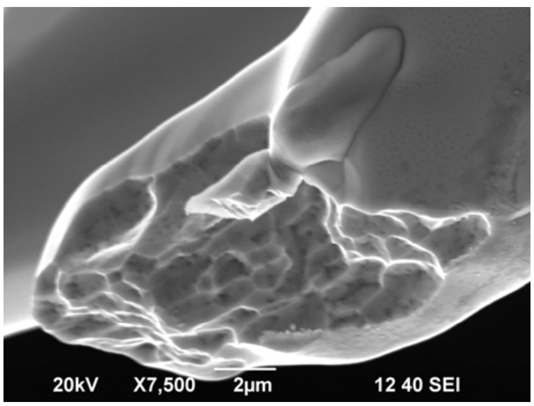
Table 19 Type 2 Hot lamp defects @ 2500 g

Aged hour	Defect Description			
	Maintained original profile	Slight deformation (Stretching & sagging)	Deformation (Snaking & tangling)	Fracture
0	0	0	8	0
10	0	0	8	0
50	0	0	6	2
100	0	0	7	1
500	0	0	7	1

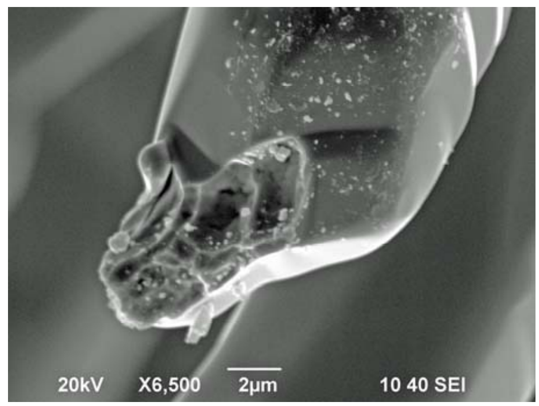
9.5 Filament Fracture characteristics

After acceleration tests of 1000 *g* and 2500 *g* for cold and hot filaments, some lamps with fractured filaments were examined using the SEM and then evaluated. Images below illustrate the distinguishable characteristics that may occur between cold and hot filament fractures.

Images in Figure 43 show the state of filaments after a cold and hot fracture. A typical cold fracture shows a formation of individual grain failures hence the material has distinctive surface defects. On the other hand a hot fracture shows a smoother rounder shape and may also display elongated necking, leading to melting at the thinnest point where the final failure occurs.



A



B

Figure 43 (A) The image on the left shows a Type 1 cold lamp aged to 500 hours displaying a fractured section with a faceted surface. (B) The image on the right shows another Type 1 lamp aged to 500 hours with a hot fracture displaying indications of melting, necking and thinning. Both lamps shown are typical failure profiles for both lamp types.

9.6 Filament orientation effects

Observation of the filaments after impact testing revealed that there is no particular trend pattern. When filaments experience an impact, the elasticity of the filaments and supporting posts allow for erratic and violent movements that can change direction quickly. This is enhanced in hot filaments where the impact generates a wave motion first one way and then another, thus producing unreliable filament effects. With cold filaments, the effects of the shockwave are less obvious and thus the filament deformation is not as severe. This can be seen in the above images Figures 20 to 42. A notable absence in cold lamps is filament tangle.

10. Estimating Lamp Operating Hours

SEM images have shown that filament surface imperfections progress as they age and that comparison of these notable differences could be used to determine an approximate burning time.

Referring to Figures 7 to 16 & D-1 it can be seen that at zero hours new filament lamps have the characteristics of the manufacturing draw-marks still present. Whereas filaments aged to 500 hours the draw-marks have disappeared and distinctive notching has occurred. The in-between stages of ageing 10, 50 & 100 hours the SEM images have shown the sequence developing.

For Type 1 Lamps:

- 10 hours of operation, the die draw-marks have disappeared and replaced with uniform scaled structure.
- 50 hours of operation; the scale has started to blend into the surface and appearance of notching has occurred.
- 100 hours of operation; continuation of the above leading onto a smooth surface with notching.

For Type 2 Lamps:

- 10 hours of operation the heat produced has blended the die draw-marks into a smooth surface.
- 50 hours of operation the filament is showing a smooth surface with minor pimples and notching.
- 100 hours of operation the filament is showing scale particles converting into a smooth surface with notching.

In each case, the filament was viewed in the mid area between the support posts. Both lamp Types 1 & 2 have shown similar degrees of deformities for their aged groups. Filament images taken near the support posts showed the scale formation on the surface was maintained up to the maximum 500 hours of ageing, suggesting that the support posts act as a heat sink. See Figure 44 for images.

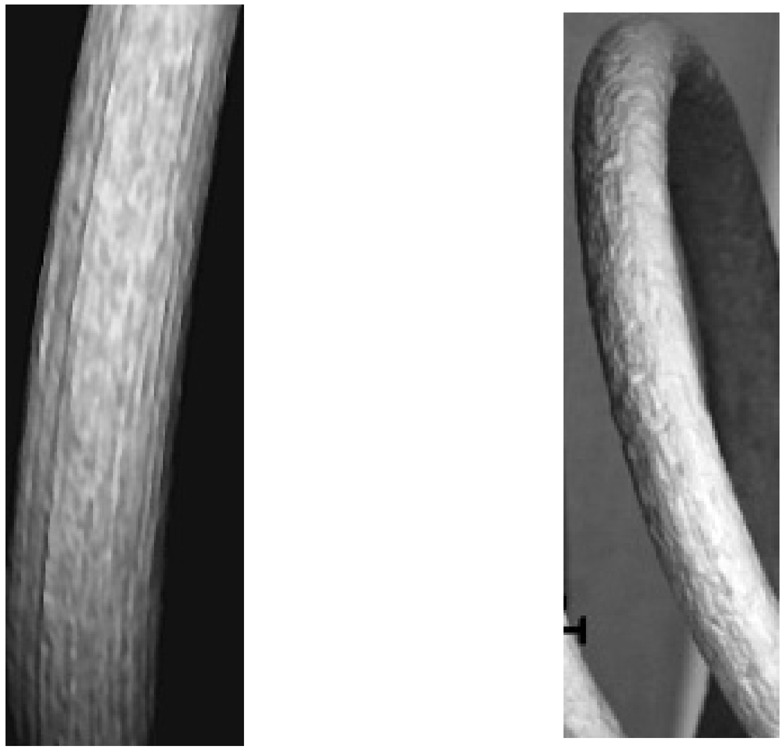


Figure 44 (A) 0 hrs Type 1 filament near support post. (B) 500 hrs Type 1 filament near support post.

11. Summary

11.1 Filament ageing

All lamps gradually develop notches on the filament which become more prominent as the number of hours of operation increase. The condition is consistent with filament material being lost while it is operating. Notch development in the vicinity of the lamp posts which support the filament noticeably lagged that at the centre of the filament. Observations of the filaments at the centre indicated that a rough guide to the number of hours of lamp operation could be estimated by reference to the nature of the notches. Suitable descriptions of the surface were found that could identify filament ages where:

1. 0 hours clearly showed the manufacturing draw marks,
2. 10 hours showed filaments with a uniform scale,
3. 50 hours showed minor protrusions and notches,
4. 100 hours showed increased notches on a smooth surface and
5. 500 hours showed significant notches.

11.2 Impact testing

Results from impact testing of 320 lamps encompassed the two filament types; Type 1 formed into a single helix and Type 2 formed into a double helix. Tests were carried out on the lamps which were aged to 0, 10, 50, 100 and 500 hours and subjected to accelerations of 1000 *g* and 2500 *g* while operating (hot) or not operating (cold). Similar findings were found for each filament type with lamps undergoing acceleration while cold differing significantly from lamps undergoing acceleration while hot. The failure behaviour under acceleration of the lamps was separated into four categories of Type 1, hot and cold and Type 2 hot and cold. Descriptions of the results have been itemised into a separate paragraph for each category to provide an overview of the results.

Type 1 lamps tested cold at accelerations of:

1. 1000 *g* left intact filaments without obvious damage,
2. 1000 *g* introduced 3 fractures, all on lamps aged to 500 hours,
3. 2500 *g* produced deformations ranging from no change to minor coil stretching, with most maintaining their pre-acceleration profile and
4. 2500 *g* introduced 15 fractures with at least one for each lamp age (2, 4, 2, 1 & 6 fractures for lamp ages 0, 10, 50, 100 and 500 hrs respectively)

Type 1 lamps tested hot at accelerations of:

1. 1000 *g* produced filament deformations ranging from no change to minor defects,
2. 1000 *g* produced one fracture on a lamp aged to 500 hours,
3. 2500 *g* produced filament deformations from slight to major with tangling, snaking and coil stretching,
4. 2500 *g* produced 1 filament fracture and
5. 2500 *g* produced 1 lamp glass envelope with a black deposit for a lamp aged to 100 hours.

Type 2 lamps tested cold at accelerations of:

1. 1000 *g* produced deformation ranging from no change to minor coil stretching,
2. 1000 *g* produced 2 filament fractures on filaments aged to 500 hours,
3. 2500 *g* produced deformation ranging from no change to minor coil stretching and
4. 2500 *g* produced 10 filament fractures (1, 2, and 7 fractures for lamps ages 50, 100 and 500 hours respectively)

Type 2 lamps tested hot at accelerations of:

1. 1000 *g* produced on all filaments deformation ranging from no change to minor coil stretching,
2. 1000 *g* produced no filament fractures,
3. 2500 *g* produced on all filaments deformations that included tangling and snaking and
4. 2500 *g* produced 4 filament fractures (2, 1 and 1 fractures for lamp ages 50, 100 and 500 hours respectively).

Under normal operating conditions, in the absence of an acceleration of at least 1000 *g*, lamp filaments exhibited various levels of sagging, coil stretching and evidence of metal loss through evaporation. After an acceleration of 1000 *g* or greater, evidence of additional damage could be expected ranging from further filament stretching to filament fracture. Lamps that were accelerated while cold showed insufficient stretching to be reliably attributed to the impact. Extra damage of the lamp was recorded when it was operating during test accelerations. This extra damage recorded was investigated and showed the extent to which it could provide forensic evidence to determine whether the filament was in operation and hot while the lamp experienced the acceleration.

Filament fractures were most likely for lamps tested with cold filaments at 2500 *g*. For Type 1 lamps there were 18 fractures for lamps tested cold and 2 fractures for lamps tested hot. Type 2 lamps produced 12 filament fractures for lamps tested cold and 4 fractures for lamps tested hot at 2500 *g*. Two types of filament fracture were identified which could distinguish between those that occurred when the filament was hot and those that occurred while the filament was cold. Those that occurred while the filament was hot displayed stretching and melting at the ends. The melting was evident from the smoother surface and rounded or ball shaped ends at the two ends of filament at the fracture point. Cold fracture ends showed evidence of a clean brittle break.

On occasions a glass envelope cracked or broke exposing the filament to air. This produced no effect on a cold filament whereas a hot filament quickly oxidised at a point which quickly evaporated and fractured. When this occurred, the glass envelope blackened with a film of metal that originated at the hot spot where the filament failed. In most cases the glass envelope retained its integrity and the filaments stretched during operation.

Observation of lamps after acceleration tests showed that the support posts remained unchanged and rigid; it also revealed that the associated filament damage did not provide a reliable way of determining the direction of an impact. For impacts on cold filaments there was little movement and there was no observable difference between lamps accelerated in different orientations. With hot impacts the filaments stretched and moved in many directions to produce a lot of distortion which masked any details of the orientation of the lamp relative to the acceleration. Unlike the support posts which remained rigid and unchanged throughout the sequence of impact testing.

12. Conclusion

A number of observations were found to be of use when determining the state of a lamp that has been involved in an impact. From this research it was found:

a) The appearance of the filament surface can be used to estimate the lamp age where:
   1. 0 hours clearly showed the manufacturing draw marks,
   2. 10 hours showed filaments with a uniform scale,
   3. 50 hours showed minor protrusions and notches,
   4. 100 hours showed increased notches on a smooth surface and
   5. 500 hours showed significant notches.

b) Indications that a lamp was off (with a cold filament) during an acceleration of at least 1000 *g* are:
   1. the filament profile has no deformation (may have sagging due to age),
   2. a filament broken with brittle fracture appearance (might not be present) and
   3. a broken or cracked glass envelope with no glass blackening (might not be present).

c) Indications that a lamp was on (with a hot filament) during an acceleration of at least 1000 *g* are:
   1. the filament coil has deformation such as tangling, snaking and stretching,
   2. a fractured filament with rounded or ball shaped ends (might not be present and might occur randomly),
   3. a broken or cracked glass envelope with darkened metal film (might not be present) and
   4. glass fragments melted on to the filament (might not be present).

d) The orientation of a lamp during impact cannot be reliably determined by examining the damage to the filaments.

13. Acknowledgements

The author would like to acknowledge the valuable assistance from;

- WOFF Andrew Duff of RAAF Base East Sale for procuring the 320 lamps required for this evaluation.
- Mr Andrew Walton (DSTO-FB AVD) for his electronic design skills.
- Mr Chris Rider (DSTO-FB AVD) for the use of the computer software package and his knowledge and participation in the impact testing, and,
- Mr Greg Cunningham (DSTO –FB AVD) for his expert skills in the use of the SEM.

14. References

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2. NLR TR 88164 C Examination of Warning and Caution Light Bulbs after Aircraft Accidents by H.J. Kolkman, National Aerospace laboratory NLR the Netherlands. (Restricted)

3. NLR CR 90026 C Further investigation into the Impact Behaviour of Aircraft Warning and Caution Light Bulbs by H.J. Kolkman, National Aerospace laboratory NLR the Netherlands. (Restricted)

4. TP 6255E A Guide to Light Bulb Analysis in support of Aircraft Accident Investigation by M. R. Poole & M. Vermij, Transportation Safety Board of Canada.

5. Topic 823 of the Traffic Accident Investigation Manual Lamp Examination for On or Off in Traffic Accidents by J. Stannard Barker, Thad L. Aycock and Thomas Lindquist, Northwestern University Traffic Institute

Appendix A: Filament Sag Data

Table A-1 Filament sag readings after ageing and prior to drop test (Type 1 Lamps 28V 40mA). Units mm

Hrs	For drop test	Lamp Identification																Mean
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
0 New	Hot	0.019	0.016	0.0	0.033	0.011	0.017	0.012	0.019	0.005	0.005	0.024	0.018	0.015	0.043 Kinked two places	0.034	0.015	0.018
0 New	Cold	~~0.0 SEM~~ *0.0 Repld*	0.025	0.041	0.010	0.012	0.005	0.037	0.032	0.014	0.023	0.0	0.025	0.015	0.021	0.0	0.0	0.016
10	Hot	0.296	0.285	0.176	0.320	0.290	0.337	0.226	0.240	0.214	0.249	0.240	0.202	0.260	0.289	0.243	0.265	0.258
10	Cold	~~0.217 SEM~~ *0.193 Repld*	0.208	0.233	0.200	0.179	0.220	0.215	0.257	0.168	0.191	0.218	0.253	0.205	0.188	0.254	0.180	0.210
50	Hot	0.276	0.213	0.169	0.264	0.175	0.238	0.246	0.223	0.250	0.256	0.248	0.224	0.254	0.275	0.236	0.257	0.238
50	Cold	~~0.264 SEM~~ *0.208 Repld*	0.181	0.267	0.260	0.205	0.202	0.280	0.250	0.310	0.148	0.218	0.186	0.200	0.238 Stretched wire, straight section	0.223	0.234	0.226
100	Hot	0.269	0.280	0.282	0.230	0.252	0.238	0.260	0.267	0.290 Kinked wire	0.211	0.253	0.194	0.263	0.215	0.228	0.283	0.251

Hrs	For drop test	Lamp Identification																Mean
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
100	Cold	0.215 SEM *0.270 Repld*	0.230	0.284	0.205	0.274	0.141	0.190	0.244	0.274	0.184	0.274	0.193	0.224	0.283	0.233	0.246	0.234
500	Hot	0.220	0.220 Broken filament *0.211 Repld*	0.185 Inverted sag & dark glass	Broken filament *0.163 Repld*	0.256	0.179	0.169	0.170	0.313	0.169	0.234	0.179	0.168	0.160	0.283 Broken filament *0.220 Repld*	0.279 Broken filament *0.215 Repld*	0.201
500	Cold	Broken filament SEM *0.269 Repld*	0.289	0.160	0.142	0.250	0.198	0.241	0.209 Broken filament *0.231 Repld*	0.312	0.348	0.260	0.13	0.266	0.257	0.234 Broken filament *0.230 Repld*	0.185	0.241

Table A-2 Filament sag readings after ageing and prior to drop test (Type 2 Lamps 28V 24mA). Units mm

Hrs	For drop test	Lamp Identification																Mean
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	
0 New	Hot																	
0 New	Cold	SEM *Repld*																
10	Hot					Broken filament *Repld*												
10	Cold	SEM *Repld*																
50	Hot													Broken filament *Repld*				
50	Cold	SEM *Repld*																
100	Hot																	
100	Cold	Broken filament *Repld*								*Broken filament *Repld*		SEM *Repld*						
500	Hot							*Broken filament *Repld*	*Broken filament *Repld*				*Broken filament *Repld*	*Broken filament *Repld*				
500	Cold	Broken filament *Repld*			*Broken filament *Repld*	*Broken filament *Repld*	*Broken filament *Repld*	*Broken filament *Repld*	*Broken filament *Repld*			SEM *Repld*					*Broken filament *Repld*	

No change, all specimens parallel. 0.000

Referring to Tables A-1 & A-2, specimens that have been labelled:

- SEM – indicates the lamp glass envelope was removed, to enable hi-magnification viewing of the filament.
- Broken filament – these specimens failed during the ageing process.
- Repld – indicates these lamps were replaced with equivalent aged lamps, therefore the required numbers for drop testing was maintained.

Appendix B: Filament profile Type 1 lamps

Images in Figures B-1 & B-2 are filament profile variations for Type 1 cold lamps, before and after acceleration at 1000 *g* & 2500 *g* when aged at 0, 10, 50, 100 and 500 hours.

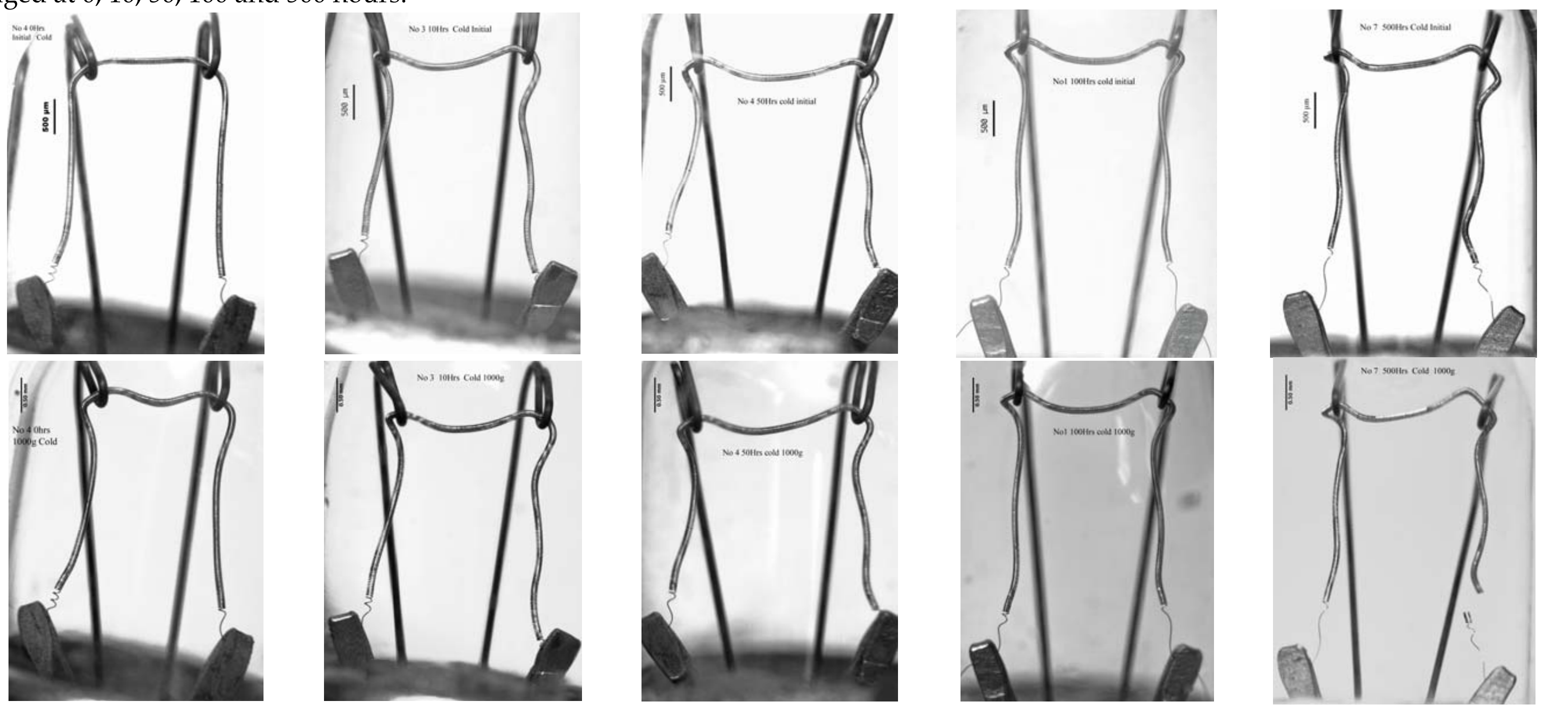

Figure B-1 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 1000 g when not illuminated.

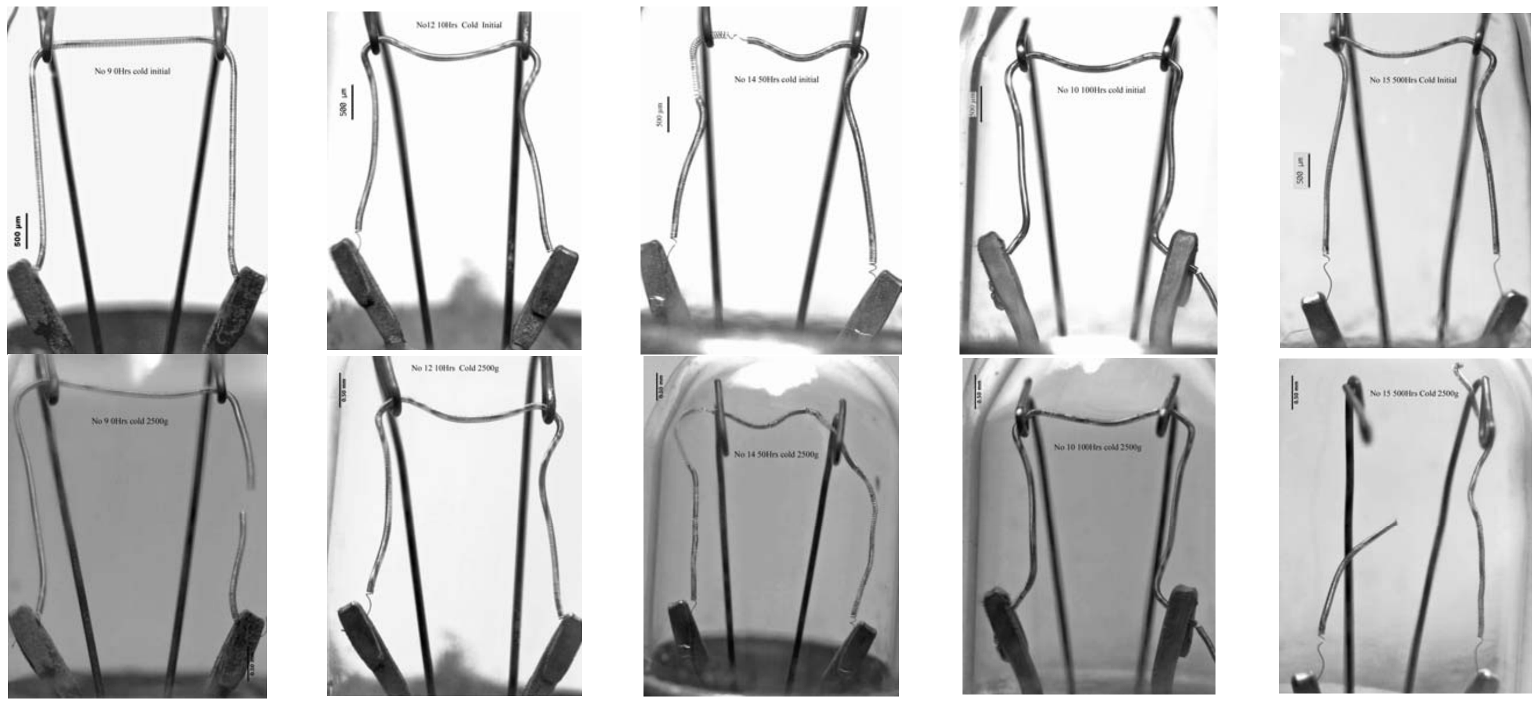

Figure B-2 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 2500 g when not illuminated.

Images in Figures B-3 & B-4 are filament profile variations for Type 1 illuminated lamps, before and after acceleration at 1000 & 2500 *g* when aged at 0, 10, 50, 100 and 500 hours.

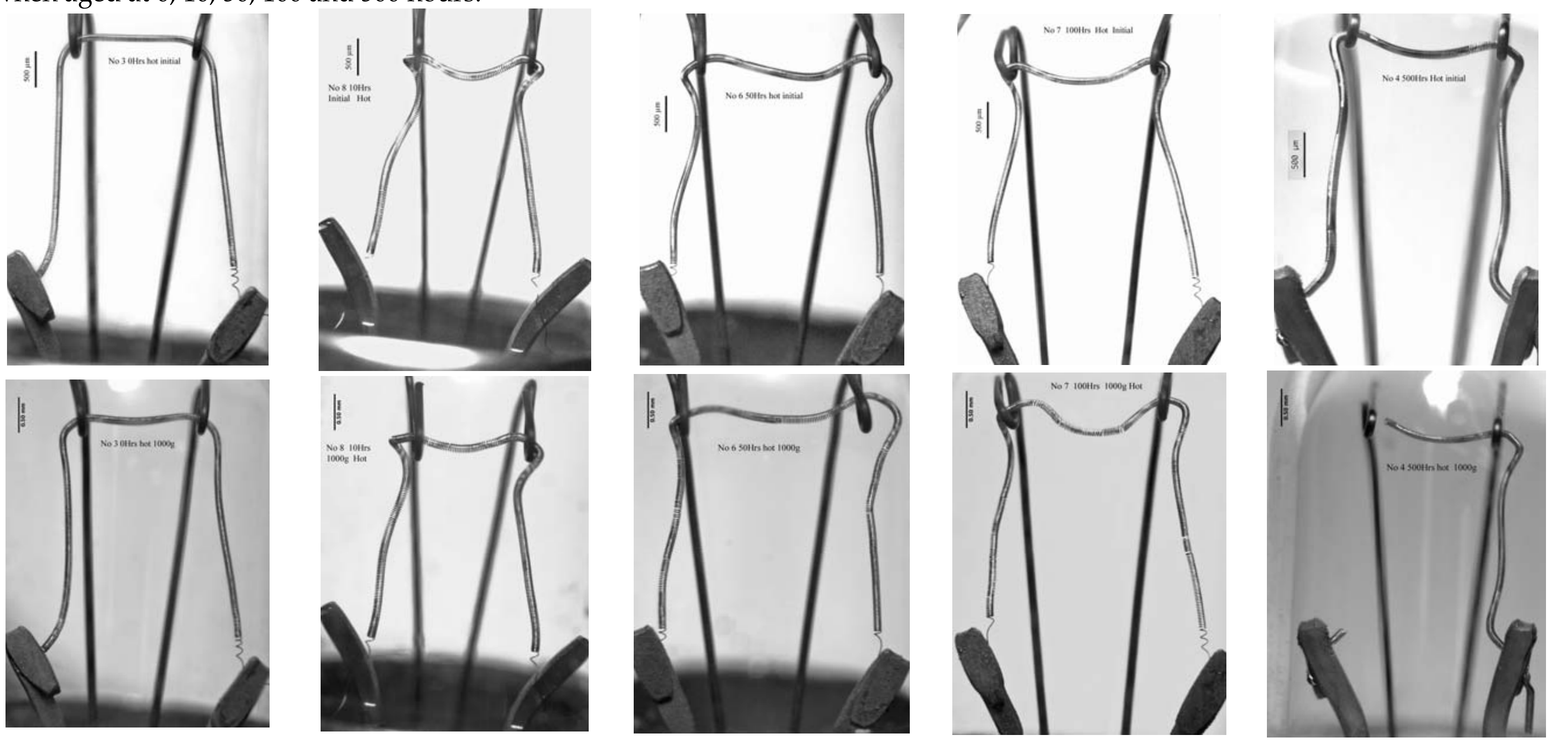

Figure B-3 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 1000 g when illuminated.

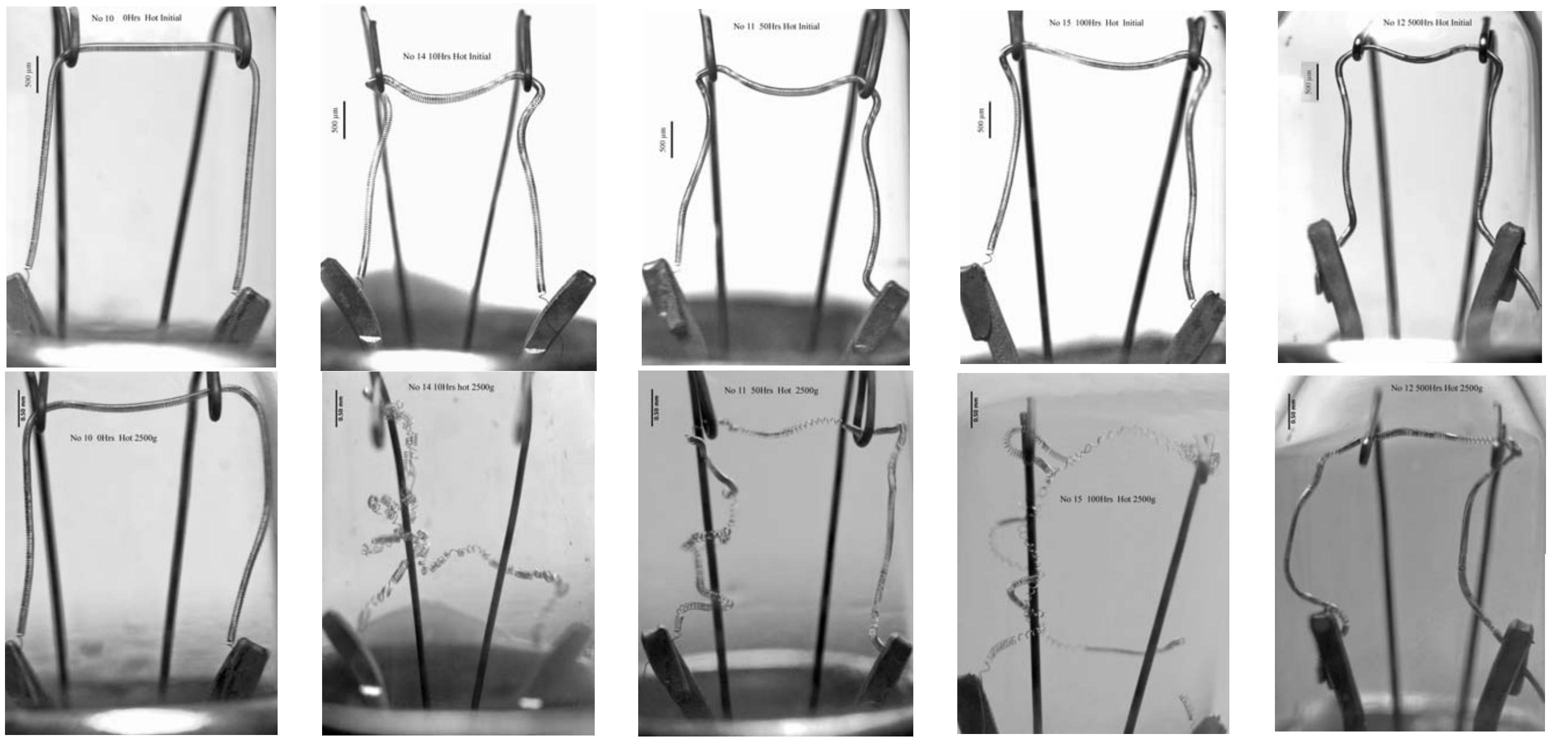

Figure B-4 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 2500 g when illuminated.

Appendix C: Filament profile Type 2 lamps

Images in Figures C-1 & C-2 are filament profile variations for Type 2 cold lamps, before and after acceleration at 1000 *g* & 2500 *g* when aged at 0, 10, 50, 100 and 500 hours.

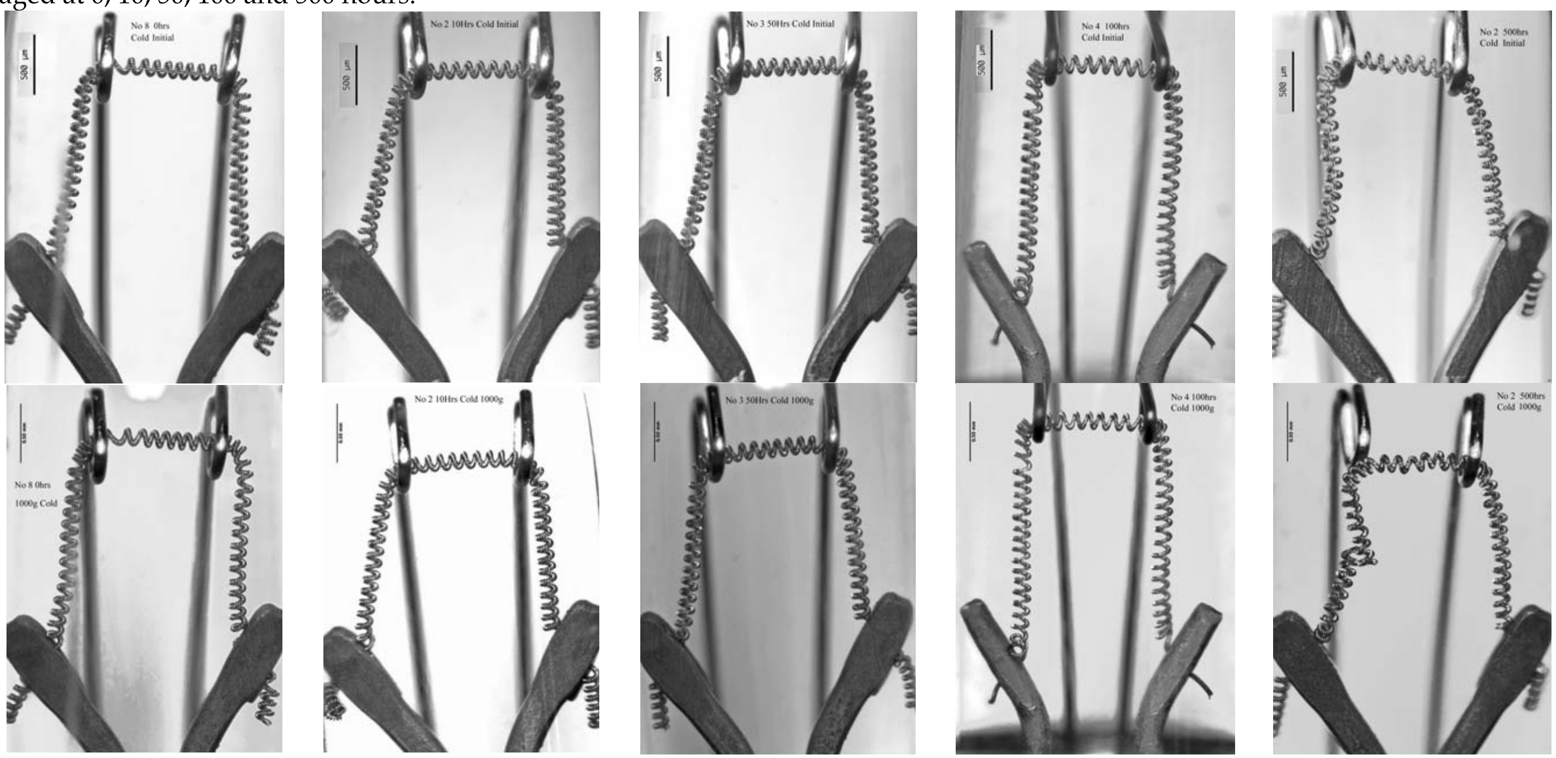

Figure C-1 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 1000 g when not illuminated.

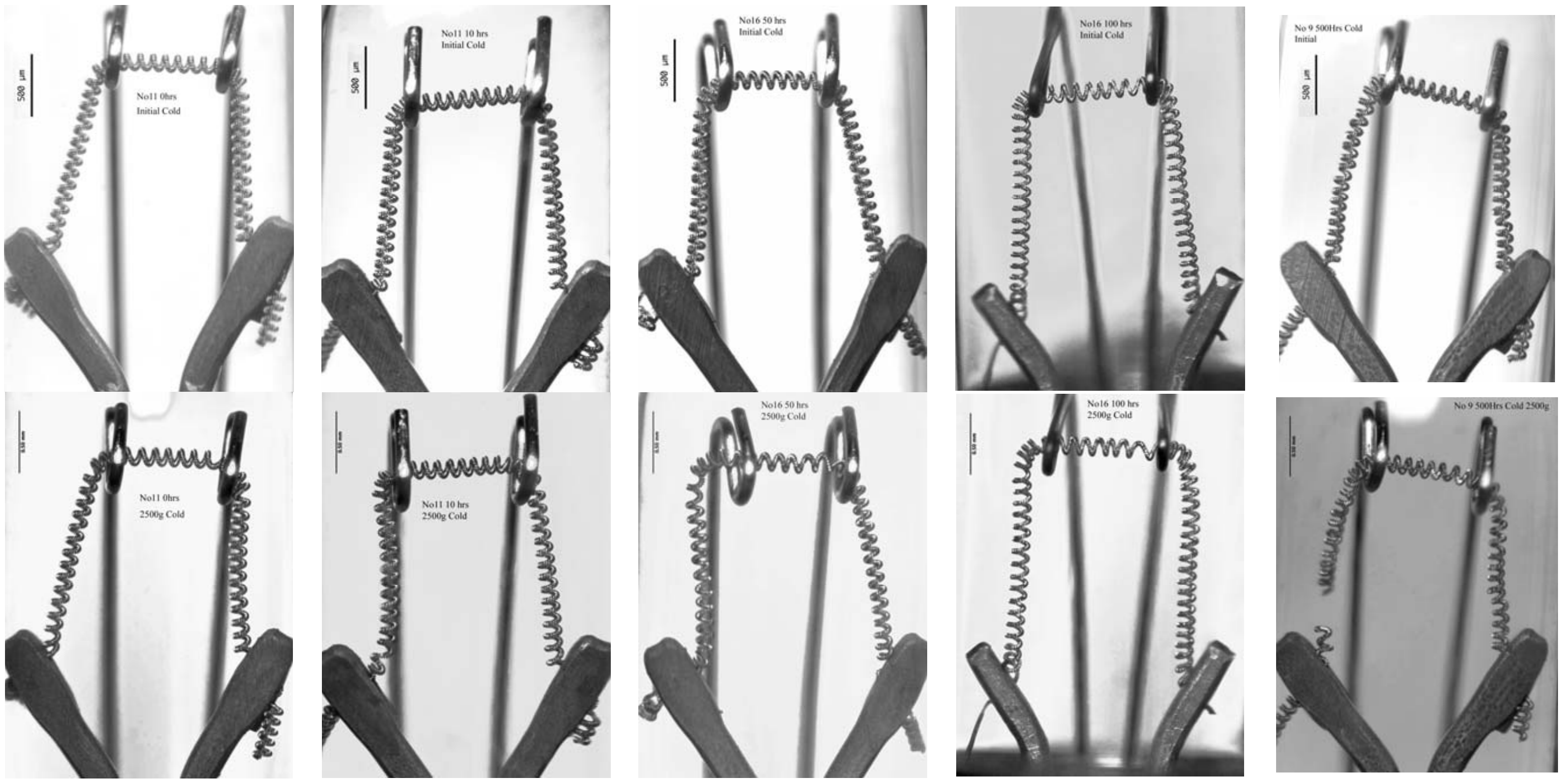

Figure C-2 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 2500 g when not illuminated.

Images in Figures C-3 & C-4 are filament profile variations for Type 2 illuminated lamps, before and after acceleration at 1000 *g* & 2500 *g* when aged at 0, 10, 50, 100 and 500 hours.

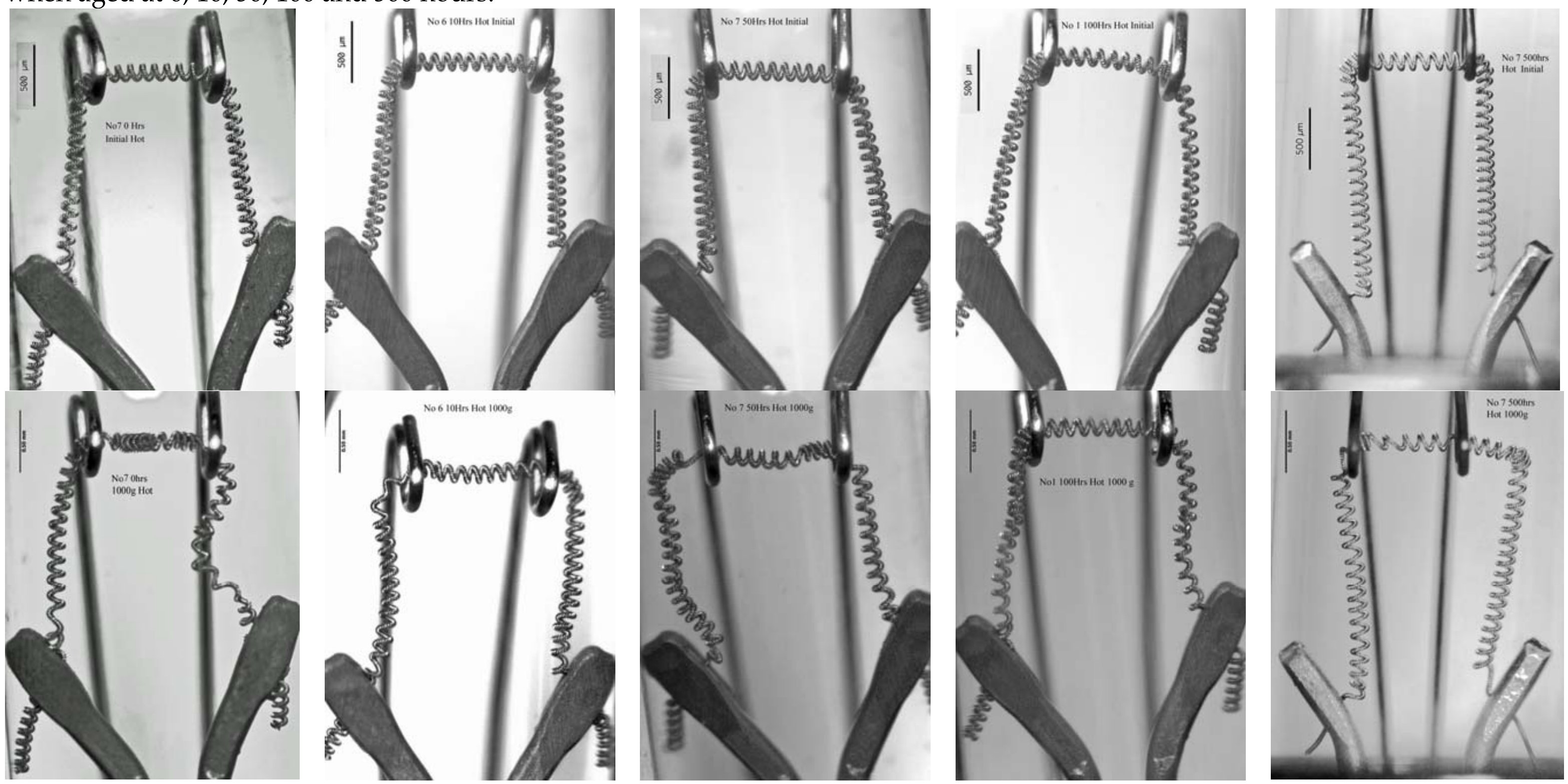

Figure C-3 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 1000 g when illuminated.

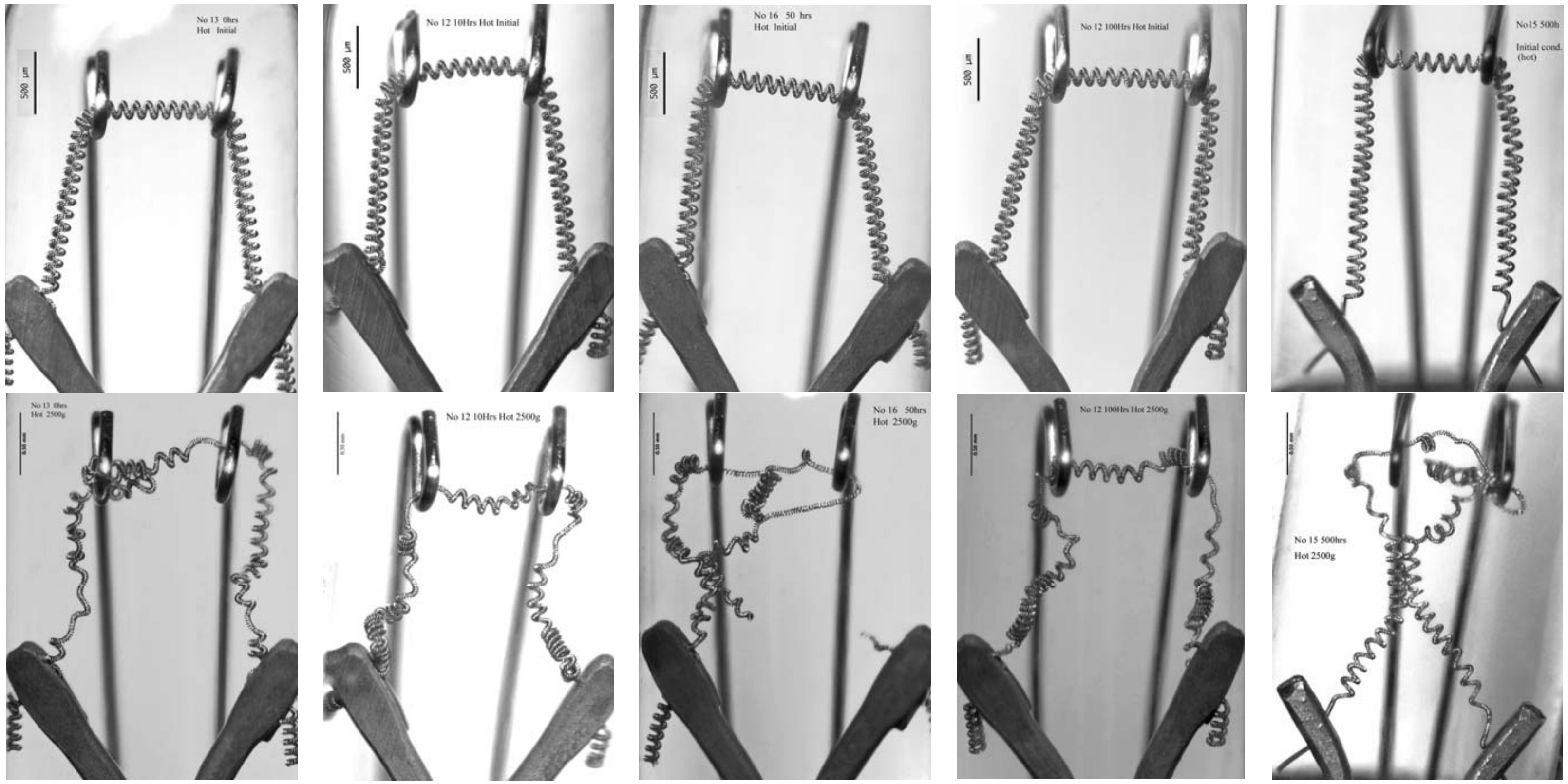

Figure C-4 The upper images from left to right show typical filament profiles prior to impact when aged 0, 10, 50, 100 & 500 hours respectively. Its lower opposite image shows the same filament after an acceleration of 2500 g when illuminated.

Appendix D: Filament ageing profile

Images in Figure D-1 show the sequence of a typical filament ageing, this is representative for both Type 1 & 2 lamps.

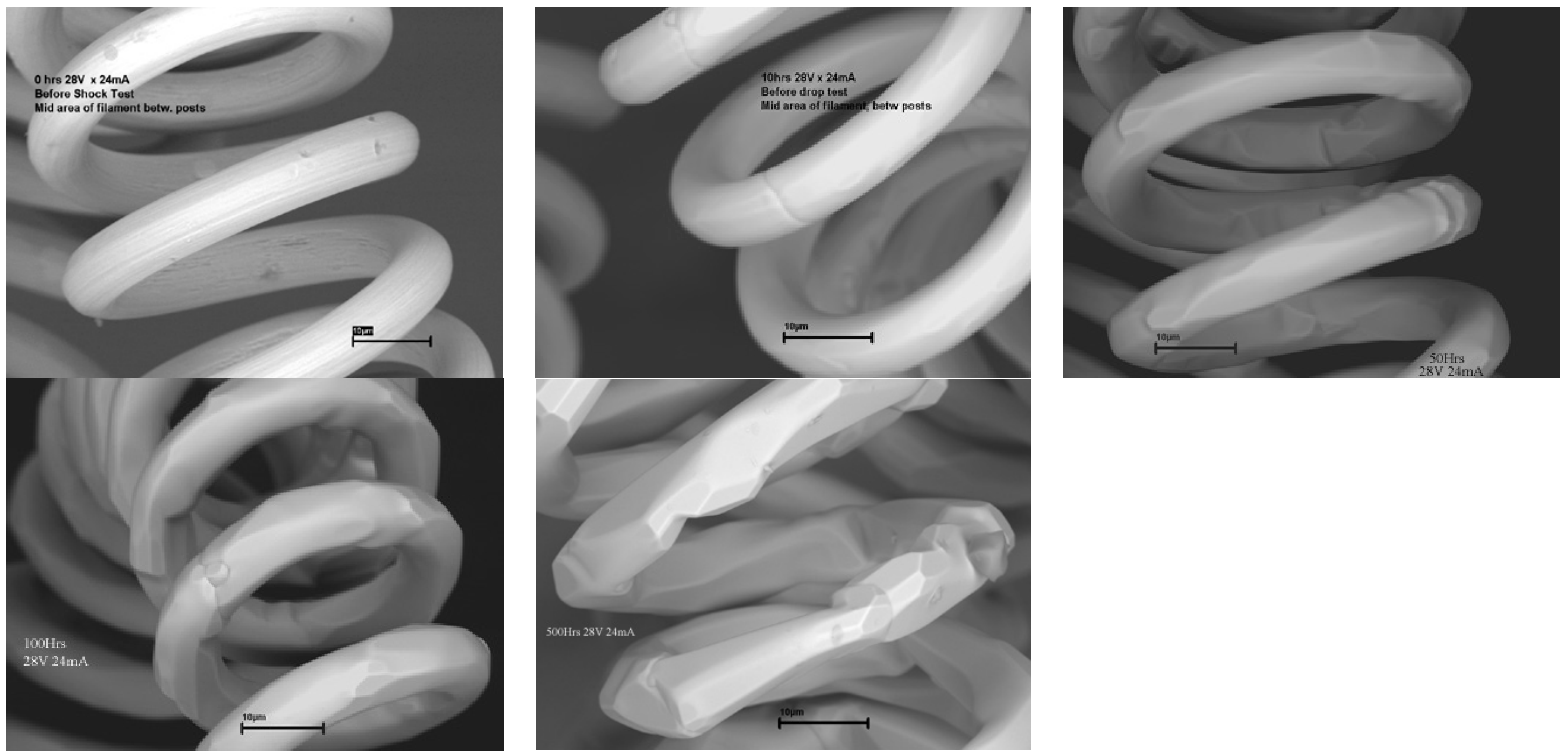

Figure D-1 Images at the mid area of a filament showing deformities. Images upper left to lower right show the filament profile when aged 0, 10, 50, 100 & 500 hours respectively.

Page classification: UNCLASSIFIED

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE Guide to the Impact Behaviour of Aircraft Instrument Panel Lamp Filaments	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) B. Grigson	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-2217	AR-014-338	Technical Report	October 2008

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2007/1101446/1	07/047	DDAAFS	71	5

13. URL on the World Wide Web	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-TR-2217.pdf	Chief, Air Vehicles Division

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Military aircraft, Instrument panels, Visual warning systems, Lamp filament, Structural damage

19. ABSTRACT
In the event of an aircraft experiencing an impact that causes significant structural damage, the examination of lamp filaments from the instrument panel warning and caution system has provided investigators with valuable information regarding the status of the aircraft systems at the time of impact. This report presents the results of lamp tests conducted at medium to high *g* impact and covers the filament condition prior and post impact, on new and aged filaments. It also provides guidelines for determining if a lamp was active just prior to the impact.

Page classification: UNCLASSIFIED