AEROSPACE INFORMATION REPORT

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(R) Ultraviolet (UV) Laser Marking Performance of Aerospace Wire Constructions

RATIONALE

The widespread use of the ultraviolet (UV) laser wire marking process for aerospace wire and cable identification is likely to lead to marking activities considering the use of this process for legacy wire types. This report provides information on updated results that have been achieved utilizing the newest generation of scanning UV laser wire markers to supplement the previous results from mask based laser wire markers during a test program intended to develop information for this purpose.

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1. SCOPE

The purpose of this report is to provide information on the results of ultraviolet (UV) laser marking and mark contrast measurement of a wide range of aerospace wire and cable constructions, the specifications for most of which do not state specific requirements for laser markability. The contents of this document are for information and guidance only. It is not intended that it be used as the basis for marking process specifications or standards, which are covered by AS5649.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of the other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR5468 Ultraviolet (UV) Lasers for Aerospace Wire Marking

ARP5607 Legibility of Print on Aerospace Wires and Cables

AS4373 Test Methods for Insulated Electric Wire

AS5649 Wire and Cable Marking Process, UV Laser

AS50881 Wiring Aerospace Vehicle

2.2 Definitions

For the purpose of this document, the following terms and definitions apply.

CABLE: Electrical cable, unless noted as a fiber optic cable. Two or more insulated conductors, solid or stranded, contained in a common covering, or two or more insulated conductors twisted or molded together without common covering, or one insulated conductor with a metallic covering shield or outer conductor.

CONTRAST: A measurement relating to the difference in luminance of the mark and its associated background according to a precise formula.

EXCIMER: A gas laser deriving its name from the term “excited dimer.” The laser is energized by means of an electrical discharge in a specialized mixture of rare gases and halogens. Excimer lasers are available operating at a number of discrete wavelengths throughout the UV, the most common of which are 193 nm, 248 nm, 308 nm, and 351 nm. The wavelength is dependant only on the gas mix used; 308 nm is commonly used for UV laser wire marking.

FLUENCE: The energy density, measured in joules per square centimeter (J/cm^{-2}) of a single pulse of the laser beam, which for the purposes of this standard is at the surface of the wire insulation or cable jacket.

INFRARED (IR): Electromagnetic radiation in the wavelength range from approximately 700 nm to in excess of 10000 nm.

INSULATION: For the purposes of this standard, the outer polymer covering of an electrical wire or multi-conductor cable or fiber optic cable.

LASER: Laser is an acronym for Light Amplification by the Stimulated Emission of Radiation. Lasers are a source of intense monochromatic light in the ultraviolet, visible, or infrared region of the spectrum. The “active” or lasing medium may be a solid, liquid, or gas; the laser beam is generated by energizing the active medium using an external power source, which is most commonly electrical or optical.

LEGACY WIRE TYPES: Wire types defined by a specification that has no laser marking requirements.

LEGIBILITY: Properties of a mark that enable it to be easily and correctly read.

LUMINANCE: The quantitative measurement of the visible light reflected from a surface; in this case, the wire or cable insulation.

MARK: A meaningful alphanumeric or machine readable mark applied to the surface of a wire or cable jacket.

MARKABILITY: The ability of a wire construction to be marked to provide legible identification marks of a specified contrast when marked in accordance with this standard.

NEODYMIUM (Nd): Neodymium is an elemental metal that forms the active laser material in the most common type of solid state laser. The neodymium is held in an optically transparent solid “host” material and is energized by optical input, either from a flash lamp or from the optical output from a diode laser. The host material does not play a direct role, but can slightly influence the laser wavelength. Typical host materials are specialized crystal materials such as yttrium aluminum garnet (YAG), yttrium lithium fluoride (YLF) and yttrium vanadate (YVO_4). These lasers are commonly referred to as Nd:YAG, Nd:YLF, and Nd:YVO_4, respectively. The primary wavelength of Nd solid state lasers is in the infrared (IR) at a wavelength of approximately 1064 nm. The IR output of such lasers can be conveniently reduced to lower wavelengths suitable for wire marking by use of harmonic generation.

PULSE LENGTH: The time interval between the laser energy crossing half the maximum energy on the rising and the falling edges of the pulse; referred to as full width half maximum (FWHM). Pulse lengths are normally measured in nanoseconds.

ULTRAVIOLET (UV): Electromagnetic radiation in the wavelength range from approximately 200 to 400 nm.

UV LASER: A laser that produces a beam of radiation in the UV range.

WAVELENGTH (λ): Wavelength is the distance between repeating units of a wave pattern, e.g., the distance between the crest of one wave and the crest of an adjacent wave. Laser wavelength is typically measured in nanometers. $\lambda = c/f$, where c is the velocity of light and f is the frequency.

WIRE: A single metallic conductor of solid, stranded or tinsel construction, designed to carry current in an electric circuit, but not having a metallic covering, sheath, or shield. For the purpose of this standard, “wire” refers to insulated electric wire.

3. BACKGROUND

A wide variety of wire constructions have been used over the years on numerous military and civil aircraft, as well as spacecraft. In many instances, it has not been considered practicable to update wire constructions to newer types on later production models due to implementation costs and potential changes that might be required in maintenance documentation and procedures. Modification programs in which new systems are added often utilize the same wire and cable types that were originally employed on the aircraft at the time of manufacture. The result has been a large scale continued use of wire and cable types that originated quite some time ago. Due to their age, the specifications for these wire and cable types predate the introduction of newer processes such as UV laser wire marking and hence do not include a requirement for markability. Such wire and cable is referred to as “legacy wire” within this document.

Over time, there have been significant improvements in process technology, including the introduction of UV laser wire marking of the type described in AIR5468 and covered by AS5649. Despite the fact that many legacy wire constructions are suitable for UV laser marking, the specifications for these constructions have not been changed to add such requirements. Also, while specifications for some modern wire constructions have been documented to include requirements for laser markability, others have not. However, the employment of titanium dioxide as a common coloring agent in most currently used white and light colored insulation materials usually permits the use of non-invasive UV laser wire marking to provide acceptable legibility and durability.

4. OBJECTIVE

When considering the possible employment of UV laser marking on various wire or cable types, organizations undertaking wire marking activities have a need to understand the levels of contrast and legibility that may be expected, the equipment needed and the fluence, pulse duration and wavelength settings required to achieve these results. The process requirements utilized for the tests are described in detail in AS5649. Aerospace vehicle manufacturers will also need assurance that the properties of individual wire and cable constructions are not adversely affected by this process.

The intent of the UV laser marking test program described in this document is to provide information about results that have been achieved when marking many of the commonly used wire types that are used in new equipment, maintenance, and modification programs. Information is also included for comparison with those few wire specifications that define a specific requirement for UV laser mark contrast.

5. WIRE MARKING PROCESS

In all cases, wires and cables were laser marked in accordance with the required process parameters specified in AS5649 in order to establish their laser marking performance.

a. In all cases, the laser specifications for the scanning based system were as follows:

- Laser wavelength = 355 nm ± 3nm
- Laser pulse length = 16 to 20 ns
- Fluence (average) = 0.8 to 1.2 J/cm^{-2}

Dot overlap of the laser marks was set to 15 to 25%. (Note that the results may not be applicable to other manufacturers' products where they use a different overlap.)

b. In all cases, the laser specifications for the mask based system were as follows:

- Laser wavelength = 355 nm ± 3 nm
- Laser pulse length = 10 to 12 ns
- Fluence (average) = 0.8 to 1.2 J/cm^{-2}

6. WIRE MARKING CONTRAST - TEST METHOD

Laser marking tests of representative samples of the wires and cables noted in Table 1 have been conducted in accordance with the requirements stated in AS4373 Method 1001, which provides an assessment of the specific level of contrast between the identification marks and the background wire insulation. This method is limited to white and to other light colored insulation materials. This method has been developed primarily to define a reproducible process of contrast value assessment for determining the legibility of identification marks. Its use is intended to provide an objective means of determination of the contrast value of wire types tested as a measure of their intrinsic laser markability.

7. TEST RESULTS

Table 1 - Typical contrast values for UV laser marked aerospace wire and cable for mask-based and scanning-based UV laser wire markers (UV LWM)

Test Specification and Wire Material			Mask-Based UV LWM	Scanning-Based UV LWM
Part Number	**Specification Source**	**Insulation Medium**	**Contrast (%)**	**Contrast (%)**
AS22759/01	SAE	PTFE and PTFE-Glass	No mark*	No mark*
AS22759/02	SAE	PTFE and PTFE-Glass	No mark*	No mark*
AS22759/03	SAE	TFE-Glass-TFE	56	61
AS22759/04	SAE	TFE-Glass-TFE	56[G]	61[G]
AS22759/05	SAE	Extruded PTFE	36	44
AS22759/06	SAE	Extruded PTFE	36-51[B]	44-55[B]
AS22759/07	SAE	Extruded PTFE	51	48
AS22759/08	SAE	Extruded PTFE	43	55
AS22759/09	SAE	Extruded TFE	38	45
AS22759/10	SAE	Extruded TFE	38-60[C]	45
AS22759/11	SAE	Extruded TFE	60	51
AS22759/12	SAE	Extruded TFE	38-60[C]	45-51[C]
AS22759/13	SAE	FEP-PVF2	Not tested[A]	Not tested[A]
AS22759/14	SAE	FEP-PVF2	Not tested[A]	Not tested[A]
AS22759/15	SAE	FEP-PVF2	Not tested[A]	Not tested[A]
AS22759/16	SAE	Extruded ETFE	90	84
AS22759/17	SAE	Extruded ETFE	90[D]	80-84[D]
AS22759/18	SAE	Extruded ETFE	90	80
AS22759/19	SAE	Extruded ETFE	90[D]	80-84[D]
AS22759/20	SAE	Extruded TFE	39[H]	39[H]
AS22759/21	SAE	Extruded TFE	39[H]	39[H]
AS22759/22	SAE	Extruded TFE	39	39
AS22759/23	SAE	Extruded TFE	39[H]	39[H]
AS22759/28	SAE	Extruded TFE	39[H]	39[H]
AS22759/29	SAE	Extruded TFE	39[H]	39[H]
AS22759/30	SAE	Extruded TFE	39[H]	39[H]
AS22759/31	SAE	Extruded TFE	39[H]	39[H]
AS22759/32	SAE	Extruded XLETFE	78-81[E]	73
AS22759/33	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/34	SAE	Extruded XLETFE	83	74
AS22759/35	SAE	Extruded XLETFE	78	73-80[E]
AS22759/41	SAE	Extruded XLETFE	78	73-80[E]
AS22759/42	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/43	SAE	Extruded XLETFE	81	75
AS22759/44	SAE	Extruded XLETFE	81	80
AS22759/45	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/46	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/51	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/52	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/53	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/54	SAE	Extruded XLETFE	78-81[E]	73-80[E]
AS22759/80	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/81	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/82	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/83	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/84	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/85	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/86	SAE	PTFE Tape Wrap	63-64[F]	60
AS22759/87	SAE	PTFE Tape Wrap	64	66
AS22759/88	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/89	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/90	SAE	PTFE Tape Wrap	63	60
AS22759/91	SAE	PTFE Tape Wrap	63-64[F]	60-66[F]
AS22759/92	SAE	PTFE Tape Wrap	63-64[F]	65