New Optical Filter Plate for Use as Eye Protection by Welders

A new protective optical filter plate was designed to improve visibility

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ABSTRACT

People whose work tasks involve the use of welding torches are at special risk of suffering eye injuries due to the emission of visible, short-wavelength radiation. Current legislation requires that a company provide its employees with protection against the harmful radiation produced by welding equipment. Often, however, a worker will be reluctant to use protective goggles since these markedly cut visibility and can consequently lead to errors or even burns. This practice of avoiding the use of protection makes them susceptible to suffer irreversible severe retinal damage leading to partial or complete loss of vision. In this paper, we propose the use of a new photoprotective filter in the form of safety goggles that seeks to improve the compromised vision produced by conventional filters. We compare a series of visual function variables in 36 adults, aged 30 to 58 years, using the new optical filter and a conventional filter used for welding protection. Our findings suggest that the filter proposed provides optimal protection against the harmful effects of short-wavelength radiation while minimizing the reduced vision effects of conventional filters used for this purpose.

Introduction

Oxyfuel welding is a process that uses fuel gases and oxygen to weld or cut metals. The flame produced by an oxyacetylene torch reaches a temperature of around 3500°C and emits radiation spanning a wide portion of the electromagnetic spectrum including ultraviolet, infrared, and visible radiation. In fact, the oxyacetylene torch emits double the radiation levels of short wavelengths compared to the remaining bands of the spectrum — Fig. 1.

Ultraviolet B (UVB) and ultraviolet C (UVC) radiation produce acute but reversible injuries such as photokeratitis and photoconjunctivitis, which cause eye swelling, tearing, intense pain, foreign body feeling, photophobia, etc. However, bright light or short-wavelength visible radiation can penetrate through to the retina causing irreversible heat and/or photochemical lesions that may lead to partial or total vision loss (Ref. 1).

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The oxyacetylene flame also produces ocular damage and irreversible loss of visual function; however, the phototoxic damage of this welding flame is not well studied because there are not mechanical elements affecting the ocular surface during the welding process.

The first documented reports of retinal damage induced by welding are the works by Terrien published in 1902 (Ref. 2). According to the literature available to date, it seems that any welding process involves risks that may lead to several forms of ocular damage and diseases (Refs. 3–8).

Photochemical retinal damage was first described in 1966 by Noell, who inadvertently noted that the retinae of experimental animals could incur irreversible damage by exposure for several hours or days to ambient light within the intensity range of natural light. Since this discovery, several studies have tried to identify the bands of the spectrum that cause most retinal damage. Thus, Noell et al. reported that retinal tissue is detrimentally affected by exposure to short wavelengths (Ref. 9). In similar studies such as the one by Okuno et al. (Ref. 5), it was concluded that the sun and arc welding, plasma cutting, and discharge lamps show effectively high radiances and that permissible exposure times are only 0.6 to 40 s, indicating that visualization of these light sources is extremely harmful to the retina (Ref. 10).

KEYWORDS

Welding
Protective Filters
Visual Acuity
Stereoacuity
Contrast Sensitivity
Light Damage

Conventional protection goggles and screens available to workers, besides absorbing the noxious bands of electromagnetic radiation, also block out 99% of the entire visible spectrum, so visibility is greatly reduced.

In the search for a device that is both protective and fails to reduce visibility, we have developed several optical filters incorporated in safety glasses to selectively block harmful light while preserving optimal vision and luminosity. The filter proposed here (UCM-AET) is composed of the plastic polymer CR-39 (allyl diglycol carbonate) with a refraction index of 1.50 (HS Monark, Spain) treated by immersion in the dyes Yellow and Gray sun (Brain Power, Inc., Florida, U.S., patent: 12/027679) (Ref. 11). The transmittance curve of the new filter illustrates how it fully absorbs the short wavelengths emitted by a welding torch (transmittance 0 in the range 400–450 nm), and attenuates the rest of the wavelengths in comparison with two conventional filters used in welding equipment — Fig. 2. This study focuses on the ocular damage induced by visible light (380–780 nm), taking for granted that all protective filters block UV and IR radiation. This study was designed to compare the visual performance using the new UCM-AET selective-absorbance filter and a conventional filter used for eye protection by welders.

Experimental Procedure

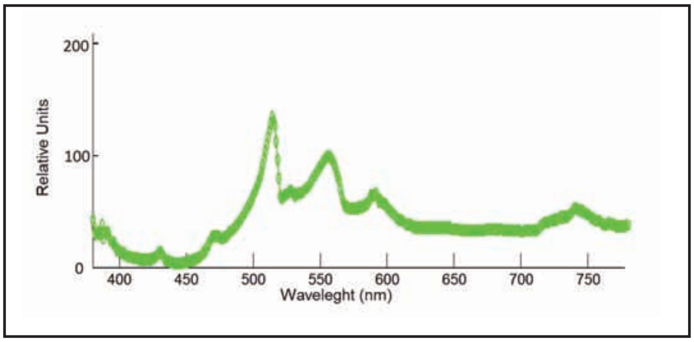

Fig. 1 — Emission spectrum of an oxyacetylene welding torch.

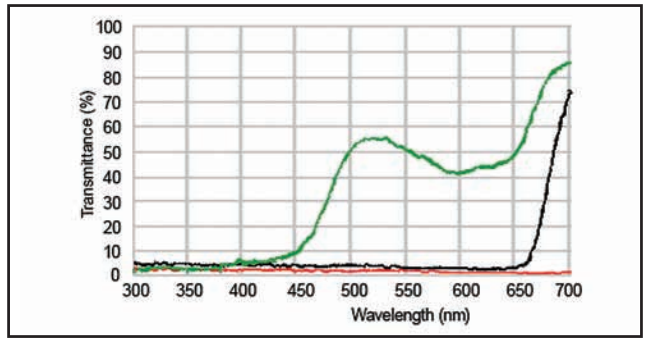

Fig. 2 — Transmittance curves of the new (green line) and two conventional protective filters for welding (red and black lines).

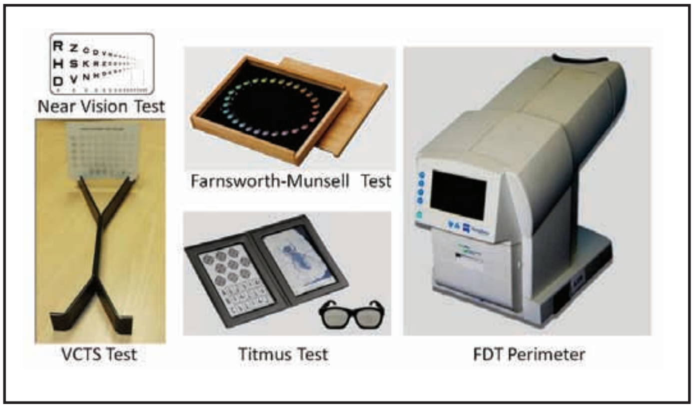

Fig. 3 — Tests used to assess vision.

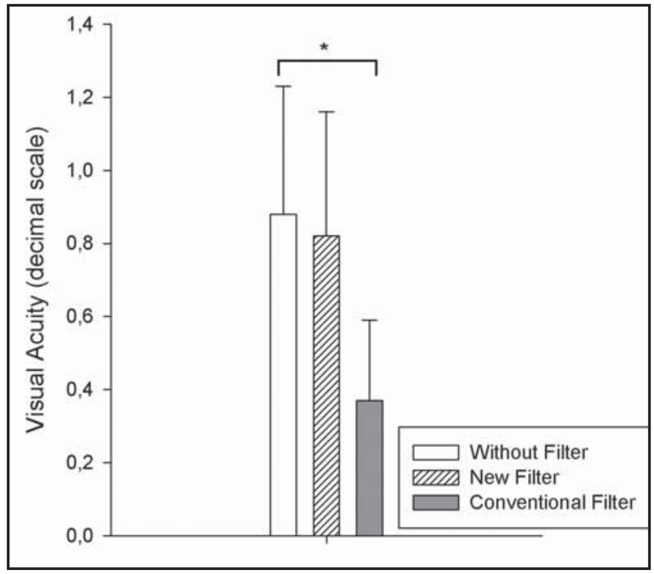

Fig. 4 — Mean visual acuity recorded with/without the use of a protective filter.

Materials and Equipment

Study participants. A prospective observational cross-sectional study was performed on 36 adults aged 30 to 58 years. All participants provided their written informed consent, and all experiments were approved by the Ethics Committee of Hospital Clínico San Carlos. We included working-age subjects of both sexes. The only exclusion criterion was an unwillingness to provide informed consent.

Experimental procedure. All participants completed a series of tests designed to assess binocular vision and monocular visual field under three treatment conditions: 1) without a protective filter, 2) with a conventional protective filter used by welders, and 3) with the new absorbance-selective AET-UCM filter. All tests were performed under normal work photopic luminance conditions. This meant that measurements were made with best-correction for near distance tasks if needed. The variables determined were binocular visual acuity, contrast sensitivity, stereoacuity, color discrimination, and central and paracentral contrast threshold. The tests described below (Fig. 3) were performed randomly, with or without the use of a filter, which was also random.

Traditional Runge near vision pocket card (Precision Vision, U.S.). This test was used to determine near-distance (40 cm) visual acuity. The test card comprises 16 letter sizes that measure visual acuities of 20/500 to 20/16. As the subject reads the letters, the examiner records the smallest sized letter the individual is able to read.

Titmus. Stereoacuity or depth perception was assessed using the Titmus test, which consists of two slightly different images, or anaglyphs, dissociated by means of polarized filters, that stimulate each retina. The variable assessed was the inverse of binocular disparity measured in radians. Each eye selects the image corresponding to its filter and as these are fused the visual system perceives the depth simulated. The test was developed by Stereo Optical Co. and is performed in three steps. In the first step, a fly is presented to the subject to measure the inverse of stereoscopic visual acuity (SVA) of 3000” of arc^{-1}. The subject puts on the polarized spectacles and the card is viewed at a 40-cm distance. The subject should be able to touch the wings of the fly in an elevated plane. If the subject's finger reaches the anaglyph, this means there is insufficient stereoacuity for good binocular vision. In the second step, three rows of animals that measure 400-200-100” of arc^{-1}, respectively, are presented to the individual who is instructed to indicate which row appears to stand out above the rest. Finally, nine series of circles are presented in which an elevation is only perceived in one circle. The subject should indicate which circle in the series is different. The scale for these circles ranges from 800” to 40” of arc^{-1}.

VCTS (Vistech Consultans, Inc., Stereo Optical Co.). This test estimates contrast sensitivity during near vision (40 cm) and is composed of circular discs arranged in 5 rows and 9 columns. Each disc contains a section of a sinusoidal grating and for each row 5 spatial frequencies (vertical) are presented corresponding to 1.5, 3, 6, 12, and 18 cycles/deg. From left to right in each row, contrast gradually decreases in 0.25-log unit steps. For each frequency level, contrast (horizontal) diminishes from left to right in 0.25-log unit steps on average. The bands are represented as different inclinations, 15 deg to the left and right and vertical. The subject is instructed to indicate the inclination

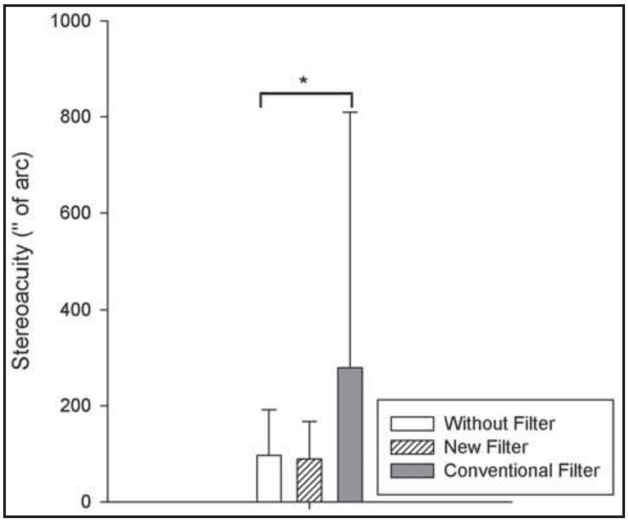

Fig. 5 — Mean stereoacuity recorded with/without the use of a protective filter.

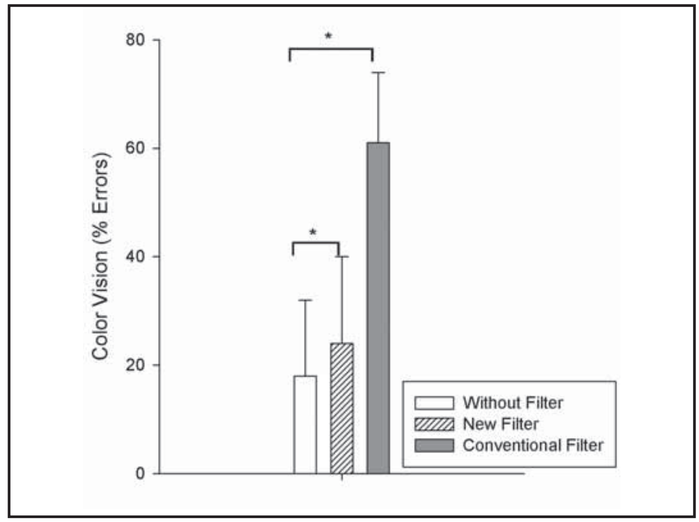

Fig. 6 — Mean color vision errors recorded with/without the use of a protective filter.

of these bands and the examiner records the minimum contrast the individual is able to perceive for each spatial frequency. This test is considered reliable to determine contrast sensitivity (Ref. 12).

Farnsworth-Munsell D-28 Hue. This test of color vision is an abridged version of the Farnsworth D-100 Hue color discrimination test. It is comprised of 28 caps (including a reference cap) that are colored according to the Munsell scale showing incremental hue variations while maintaining luminance and saturation at a given Munsell value. These hues occupy positions in the uniform color space of Farnsworth, hence, the test's name. The subject is instructed to order the caps according to hue. The caps cover different zones of color space and are numbered such that the order indicated by the subject can be recorded on a response sheet. The response order is translated to a score, which serves to detect color vision abnormalities and aptitude.

Frequency-doubling technology (FDT) perimetry. This test uses an automated instrument for visual field testing based on frequency-doubling technology. The frequency-doubling effect is achieved by a low-frequency spatial sinusoidal grating (<1 cycle/deg) undergoing counterphased flickering at a temporal frequency of 15 Hz. This determines that the number of dark and light bars appear to be twice the actual number. The test consists of taking measurements of contrast sensitivity (in decibels, dB) to detect the frequency-doubling stimulus. The FDT perimetry instrument (Humphrey Systems, Dublin, Calif., and Welch Allyn, Skaneateles, N.Y.) determines the contrast sensitivity needed to detect the stimulus at 17 or 19 locations in the central visual field. The subject fixes on the black dot in the center of the screen and presses the instrument response button when vertical bars flicker in different areas of the screen. For this study, we used the C-20 threshold presentation pattern with 17 stimulus locations. After entering the age of the subject, a preliminary familiarization test was performed on the left eye (these results were discarded) and then the contrast threshold was assessed in the right eye under the three treatment conditions.

Statistical analysis. Data were compared among the three treatment conditions to assess the effects of the filters on the different measures of visual performance. All comparisons were pairwise and

Table 1 — Values Recorded for the Different Vision Performance Variables Determined with and without a Protective Filter Designed for Use by Welders

	Without a Filter		UCM-AET Filter		Conventional Filter	
	Mean	p-value	Mean	p-value	Mean	p-value
Visual acuity						
LogMAR (40 cm)	0.1 ± 0.49		0.49 ± 0.22	0.999	–0.03 ± 0.07	0.000*
Stereoacuity						
" of arc $^{-1}$	97 ± 95		89 ± 78	0.999	279 ± 531	0.000*
Color Discrimination						
N° de errors	5 ± 4		6 ± 4	0.006*	17 ± 3	0.000*
Contrast sensitivity						
1.5 cpd	4.89 ± 0.32		4.81 ± 0.47	0.999	2.58 ± 1.36	0.000*
3 cpd	5.42 ± 0.77		5.08 ± 1	0.417	247 ± 1.56	0.000*
6 cpd	4.17 ± 1.3		3.58 ± 1.38	0.028*	1.5 ± 1.18	0.000*
12 cpd	3.44 ± 1.87		2.94 ± 1.91	0.316	0.58 ± 0.81	0.000*
18 cpd	2.81 ± 2.29		1.92 ± 1.71	0.022*	0.19 ± 0.52	0.000*
FDT Perimetry						
Central	29.49 ± 5.36		25.51 ± 4.2	0.000*	1.84 ± 2.39	0.000*
Fovea	31.36 ± 5.94		25.89 ± 3.98	0.000*	2.19 ± 3.51	0.000*

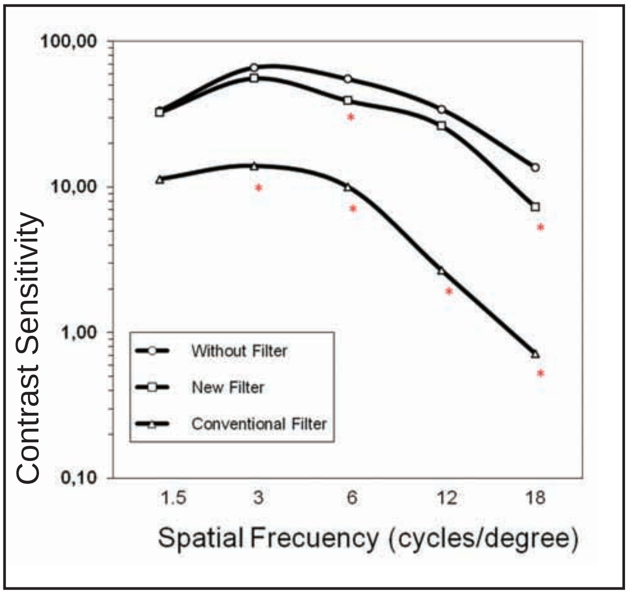

Fig. 7 — *Mean contrast sensitivity recorded with/without the use of a protective filter.*

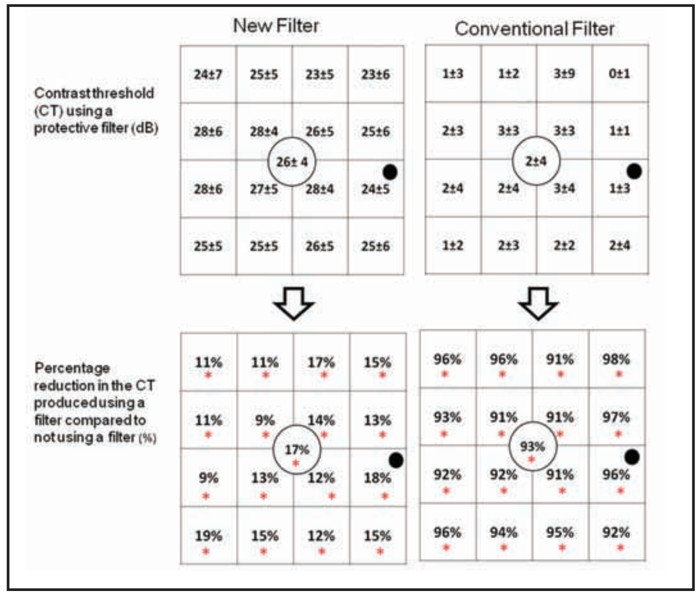

Fig. 8 — *Mean FDT visual field results recorded with/without the use of a protective filter.*

significance was set at a $p < 0.05$ and statistical power at 0.8. All statistical tests were performed using *Statgraphics Plus* 5.0 software (Professional Edition).

Results

Sample characteristics. The study participants were 36 subjects of mean age 44±14 years: 22 men (47±14 years) and 14 women (39±14 years).

Visual acuity and stereoacuity. Mean VA and stereoacuity in absence of a protective filter were 0.1±0.49 logMAR and 97±95” arc^{-1}, respectively, considered normal for this age range. Corresponding values were 0.49±0.22 logMAR and 89±78” arc^{-1} for the UCM-AET filter and –0.03±0.07 logMAR and 279±531 arco^{-1} for the conventional filter. It was observed that the lower the VA and stereoacuity, the lower was the resolution capacity of the subjects examined. These results show no significant effects induced by the new filter on near visual acuity and depth perception (stereoacuity). In contrast, these measures were significantly reduced when the conventional filter was used (Table 1) — Figs. 4, 5.

Color discrimination. This ability was determined as the number of errors produced when ordering the different hues in the Farnsworth-Munsell test. Our results show that both filters significantly compromise color discrimination — Fig. 6. The number of errors was high at around 43% for the conventional filter and much lower for the new filter with only a 5% loss of color discrimination detected (Table 1).

Contrast sensitivity. Using the UCM-AET filter, contrast sensitivity for near vision was significantly reduced for the spatial frequencies of 6 and 18 cpd, while a greater reduction was observed with the conventional filter for all the spatial frequencies tested. Thus, contrast sensitivities recorded for the new filter were closer to those obtained without a filter than the values recorded for the conventional filter — Fig. 7.

FDT perimetry. Our visual field data showed significantly reduced contrast thresholds for all zones examined using both filters although this reduction was more marked for the conventional filter. Thus, the UCM-AET filter achieved a 9–19% reduction in the contrast threshold while this was 91–99% for the conventional filter. This means that with the new filter, the contrast threshold is 76–85% improved over the normal working conditions of welders — Fig. 8.

Discussion

Some jobs involve a particular risk of eye damage due to the simultaneous presence of photothermal, photomechanical, and photochemical factors. Several studies addressing the topic have indicated a need for safety goggles or screens for welding tasks since high UV radiation levels can cause severe eye damage (Refs. 3–8). Such devices need to provide sufficient protection for the worker to undertake his/her routine work without exceeding the maximum permissible exposure (MPE) threshold. To verify that eye protection devices were able to satisfy this requirement, in 1997, Tenkate (Ref. 4) determined levels of exposure to UV radiation in a group of welders using a photosensitive polymer film to line the inner and outer surfaces of the eye protection used by the welders. The results of this study indicated that mean ocular exposure (inside the helmet) was four to fivefold the MPE, suggesting a need for additional eye protection to that provided by conventional welder’s helmets (Ref. 5). Subsequent to this, Maier et al. (Ref. 13) in 2005 and Peng et al. (Ref. 7) in 2007 examined several protective filters and concluded that these protected workers from exposure to the harmful radiation emitted by welding tools. In addition, Maier et al. admitted that macular damage in welders was a consequence of negligence in complying with safety regulations.

In another landmark study conducted by Chou et al. in 1996 at a car assembly plant, the factors described as the main risks related to welding work, besides radiation from the blow torch, were the particles of melted metal emitted in all directions (Ref. 14). This means that workers in such an environment should wear some form of eye protection that incorporates an ocular filter. However, welders often have to work in dark, restricted environments and this compromises their vision such that they frequently take off their safety goggles to complete the work (Ref. 6).

However, rather than being negligent, it seems that a welder will remove his/her safety goggles to avoid burns on hands and arms, since as shown by our results, visual acuity is reduced by up to 58% using a conventional filter. Considering that the flame from an oxyacetylene welding torch can exceed a temperature of 3500°C, optimal vision in the work field is essential to avoid burns or errors.

The filters currently used for this purpose are attenuating rather than selective filters and thus considerably impair vision to the extent that they may not be regularly used by some welders. The Industrial Safety Equipment Association (ISEA) and *Compliance Magazine* state that 68% of all employees who should use protective eyewear do not do so (Ref. 16). This is probably why an estimated 400,000 eye injuries occur on the job every year according to the American Society to Prevent Blindness (Ref. 15).

To avoid this loss of visibility while using eye protection, in this study we propose the use of a band-selective filter that only absorbs the short wavelengths in large measure and attenuates the remaining wave lengths of the visible spectrum, while blocking UV and IR radiation. This filter will therefore protect the worker from the harmful radiation and, by allowing the passage of the lower-energy wavelengths, will also improve the wearer's vision through the eye protective material.

We observed that standard approved protective optical filters incorporated in safety glasses reduce most aspects of vision by 50 to 70%. The optical filter proposed (UCM-AET) induces a reduction in visual perception of 15 to 35%, so its use can improve near vision by around 40% compared to conventional filters, providing the same level of ocular protection. Due to the increase in the visibility of the working scenario, the use of safety glasses will go and, consequently, there will be a better prevention of occupational risks of ocular damage in agreement to Maier (Ref. 13).

In general terms, a high percentage of workers routinely exposed to the phototoxic effects of light will eventually have to give up their work due to health impacts. The benefits of such a solution are therefore crucial. The new filter will protect the retinae of welders while enabling them to see sufficiently well to perform any detailed task and avoid the risk of burns. The filter proposed also has the benefit that it is an easy and economical solution to the problem addressed.

Conclusions

1) To promote the regular use of eye protection in the welding environment, a protective component is required that will not reduce the visual acuity of the worker. The absorbance-selective UCM-AET filter does not affect the visual acuity, while a standard filter reduces the resolution capacity of the wearer by more than half.

2) The new filter is recommended to avoid work accidents involving skin burns produced by poor visibility in the work environment.

3) The new filter is also recommended for detailed welding work since, unlike the situation with the conventional filter tested, depth perception is unaffected.

4) Although both the new filter and the standard filter diminish the user's ability to discriminate colors, this effect was more marked for the conventional filter.

5) The UCM-AET filter absorbs short wavelengths of light but transmits medium and long wavelengths. This allows for improved visibility in the work field since practically normal contrast thresholds are maintained. Conversely, contrast thresholds were reduced four fold compared to the values recorded without a filter, thus increasing the risk of accidents or of a worker not using the required eye protection.

6) The different aspects of vision were dramatically reduced when the conventional filter was used. In contrast, the new filter was able to avoid or minimize these effects emerging as a good protection system for welders along with their habitual spectacle correction used for work activities.

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