EFFECTIVENESS OF ULTRAVIOLET LIGHT PERSONAL PROTECTIVE EQUIPMENT USED BY INFORMAL SECTOR ARC WELDERS IN MACHAKOS TOWN, KENYA

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Abstract
The purpose of the study was to evaluate the suitability of the ultraviolet (UV) light personal protective equipment (PPE) used by arc welders in the informal sector. Primary data were collected through a survey in the study area and through laboratory test of the identified UV light PPE's filter plates. A sample of one hundred and three arc welders in the study area was accessed through snowball sampling technique since cases were affiliated through links that could be exploited to locate other respondents based on existing ones. The study involved both the owners of the workplaces and their staff operating in the Kenya Industrial Estates (KIE) sheds, Masaku Jua Kali Association sheds and the individual arc welders operating along the streets of Machakos Town, Kenya. All the arc welders who participated in the study except one were 18 years and above in age and all had formal education: 31.1% had primary school level as the highest attained education level, 34.9% had secondary school level as the highest attained education level and 34.0% had been to tertiary learning institutions. The field survey identified nine types of UV light PPE used by the study group. The PPE were identified by the distinct features on their filter plates: shade number 12, shade number 11, gas goggles, dark dots, dark vertical lines, dark horizontal lines, dark spiral lines, dark nucleus and obstruct glass. Absorbance of each filter plate at λ_{max} in the UV range of the electromagnetic spectrum was determined so as to calculate the corresponding shade number. The absorbance values matched that of shade number 12, 11, 9 and 8. The study found out that 63.1% of the arc welders used shade numbers 8 and 9 both of which were below the minimum recommended shade number 10 for arc welding in the lense selection guide. The effectiveness of the UV light PPE used was influenced by the highest level of education attained by the arc welder, the age of the welder and the number of years the welder had worked as arc welder in the informal sector ($p < 0.05$). The peculiar nature of the activities constituting arc welding in the informal sector requires modified goggles with scientific proof of their effectiveness and not hand-held welding shield or the welding helmet.

Key words: Personal protective equipment, arc welder, informal sector/jua kali, ultraviolet light, shade number, filter plate

1.0 Introduction

According to EUdict (2011), welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. Several welding techniques exists which include shielded metal arc welding, now one of the most popular welding methods; gas metal arc welding; submerged arc welding; flux-cored arc welding and electroslag welding (Cary and Helzer, 2005). Arc welding is one of the several fusion processes for joining metals where the mechanical and physical properties of the base materials can be duplicated at the joint, contrary to the non-fusion processes (Lincoln Electric, 1994). Technological advancement and use of PPE play a key role in reducing the hazards (e.g. electricity, heat, sparks, smoke/fumes, noise, UV light among others) associated with arc welding (Cary and Helzer, 2005). According to Kane and Kumar (1999), cataracts, macular degeneration and corneal damage are all likely chronic effects from UV exposure and can eventually lead to loss of sight. Arc eye as per Lincoln Electric (1994) is a condition caused by the brightness of the weld area in which the emitted UV light leads to inflammation of the cornea and can burn the retinas of the eyes. Occupational risks are as a result of interactions between the worker, operations and hazards at the workplace (Roy, 2003). According to Management of Health and Safety at the work Regulations (1999), although the approach adopted for health and safety control should provide a balanced portfolio of physical, management and human factor measures, it is normal to take into account what is referred to as the hierarchy of control principle. The hierarchy of control presents six levels namely elimination, substitution, engineering controls, administrative controls, PPE and workplace monitoring/surveillance. PPE refers to appliances designed to guard the user's body against the hazard. PPE in the hierarchy of control is ranked fifth and is used to provide a back-up or second line of defense to an engineering control measure or a safe systems of work as per Colin and Luise (2004). The Occupational Safety and Health Act (OSHA, 2007) requires the protection of eyes in certain processes such as welding or cutting of metals by means of electrical oxyacetylene or similar processes. Further, the Factories (Protection of Eyes) Rules (1978) require that eye protectors be appropriate to a specified process. It is important that welders be appropriately clothed and protected because of the heat, UV light, noise, and sparks produced during welding. A welding helmet or hand-held welding shield with filter plate and cover plate is mandatory for eye protection from the harmful rays of the arc. The filter plate should be at least shade number 10 for general welding up to 200 amperes (OSHA, 2003).

2.0 Materials and Methods

2.1 Sampling

The study was carried out in Machakos town situated at coordinates 1^0 31’ 0” South, 37^0 16’ 0” East, 64 kilometres southeast of Nairobi city, Kenya. Machakos town being a major rural centre in Machakos County and a satellite town due to its proximity to Nairobi city presents a settled informal sector with relatively equal influence from

urban and rural activities. This therefore makes it an ideal study area by set up, operations and products. As per the Machakos District Labour office, Machakos District Development office, Machakos County Government head offices, KIE office in Machakos and Masaku Jua Kali Association, arc welders in Machakos town are approximately 1,000. The required data to meet the study objectives were continuous and a margin of error of 0.03 was appropriate. Bartlett, Kotrlik & Higgins' (2001) published tables for a population size of 1,000 at an alpha level of 0.05 for continuous data gives a sample size of 106. A survey using a structured questionnaire, structured interviews, site visits and field observations was undertaken in the study area to identify the UV light PPE used by the target population. Snowball sampling was employed in the survey since it was assumed that subjects are affiliated through links that could be exploited to locate other respondents based on existing ones (Hagai, 2006). The researcher accessed 103 arc welders representing 97.2% of the calculated sample size which was acceptable.

Filter plates of the identified UV light PPE were bought for laboratory test. Shade number 10, 11, 12 and the Gas Goggles filter plates were readily available in hardware shops, hence the researcher bought his own samples for analysis. The other samples with the guiding features best known to the users were bought from the welders since they had unused ones which they sold to the researcher. A *Shimadzu* UV-VIS 8000 Spectrophotometer shown in Plate 1 was used in the study to measure the absorbance of each of the samples (filter plate of the identified UV light PPE). Every sample was first cleaned using distilled water, dried and mounted on the path of radiation from the source and a clear glass was used as the reference (blank). The instrument parameters were set to scan the entire wavelength of the spectrophotometer i.e. 1100 – 190nm and the absorbance value set to read ± 4.00 absorbance units but attention was mostly laid on λ_{max} at the UV region of the electromagnetic spectrum that is 190 – 400nm.

Plate 1: Shimadzu UV-VIS 8000 Spectrophotometer

Absorbance at λ_{max} for each of the samples was used to determine the sample's shade number whereby:

$$SN = \frac{7(-\log_{10} T)}{3} + 1$$ (Russ, 2004) ..... (i)

But, $A = -\log_{10} T$ (Patnaik, 2004) .....(ii)

$$\therefore SN = \frac{7}{3}A + 1$$ ..... (iii)

Where,

SN = Shade Number
T = Transmittance
A = Absorbance

Determination of the samples' shade number as per equation (iii) above, facilitated the comparison of the obtained results with the standard. The standard used was the lense selection guide as adapted from ANSI Z49.1 (1999). Secondary data included: reference filter plates used namely shade number 10, ordinary goggles and clear glass; and sited literature from libraries, internet and various publications.

3.0 Results and Discussion

The data were analyzed using Statistical Package for Social Sciences (SPSS) Version 16.0.

3.1 Preferred UV Light PPE's Shade Number

Laboratory test conducted on the nine samples from the identified UV light PPE through the survey in the study area revealed that the samples were shade numbers 8, 9, 11 and 12 as shown in Table 1 below together with the reference plates used.

Table 1: Shade numbers

Sample	λ_{max} (nm)	Absorbance	Shade Number as per equation iii above
Shade number 11 filter plate	321	> 4	11
Shade number 12 filter plate	399, 300, 285	> 4	12
Gas goggles filter plate	214	3.4	9
Dark dotted filter plate	378, 368	3.6	9
Dark vertical lined filter plate	337	3.4	9
Dark horizontal lined filter plate	376	3.6	9
Spiral lined filter plate	346, 207	3.7	9
Filter plate with a dark nucleus	220	3.5	9

Sample	λ_{max} (nm)	Absorbance	Shade Number as per equation iii above
Obstruct glass filter plate	224	3.2	8
Shade number 10 filter plate (reference)	377	3.8	10
Ordinary goggles filter plate (reference)	203	0.8	3
Clear glass filter plate (reference)	351, 339, 346	0.6	2

The study as shown in Table 2 found out that most of the arc welders (63.1%) used shade number 8 and 9, both of which are below the minimum shade number for arc welding. Only 36.9% used shade number 11 and 12 which are above the minimum value.

Table 2: Preferred UV light PPE's effectiveness

Shade Number	n	%
8	3	2.9
9	62	60.2
11	34	33.0
12	4	3.9
Total	**103**	**100.0**

3.2 Problems the respondents experienced while arc welding using the Preferred UV light PPE

There was strong relationship between the preferred UV light PPE used by arc welders and the problems the arc welders experienced during welding ($p < 0.05$). This relationship may be attributed to the peculiar nature of the activities constituting arc welding in the informal sector. As shown in Figure 1, the group of respondents who had no problems (i.e. None) while welding with the UV light PPE of preference was dominated by welders who used shade number 9 representing 29.1% of the total respondents in the study, followed by the welders who used shade number 11 constituting 5.8% of the study respondents, then the welders who used shade number 8 constituting 2.9% of the respondents in the study and the least were the welders who used shade number 12 representing 1.9% of the total respondents in the study. The respondents who reported that the UV light PPE of preference was tiresome/cumbersome used either shade number 11; representing 27.2% of the study respondents or shade number 12; constituting 1.9% of the total study respondents. All the respondents who used shade number 8 as their UV light PPE of preference had no problem with the PPE during arc welding. Half of the respondents who used shade number 12 had no problem during arc welding whereas the rest who used UV light PPE of shade number 12 reported that the PPE

was tiresome/cumbersome as per the study. Likewise, all those who reported that their UV light PPE of preference lead to working at awkward/bad posture used UV light PPE of shade number 9, representing 24.3% of the respondents. Further, those who reported that their UV light PPE of preference during arc welding subjected them to face burns all had used UV light PPE of shade number 9 representing 6.8% of the respondents.

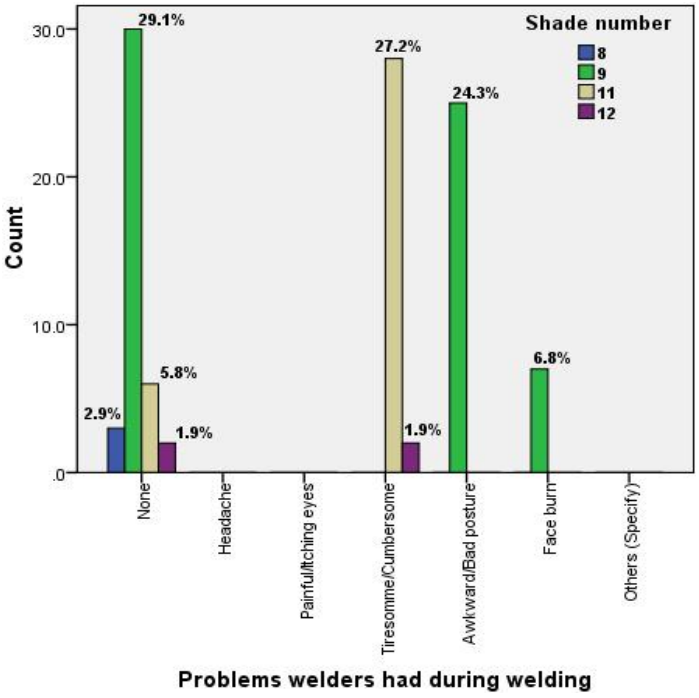

Figure 1: Problems the respondents experienced during arc welding

3.3 Problems the Respondents Experienced after Arc Welding Using the PPE of Preference

The study established significant relationship between the shade number of the UV light PPE used and the problems welders experienced after arc welding ($p < 0.05$). Most of the respondents who reported eye related problems after arc welding used a shade number below the minimum shade number for arc welding, an indication that the PPE was subjecting the user to UV light. Figure 2 shows that 1.9% of all the respondents suffered from headache and painful/itching eyes while 1.0% suffered from headache and pain at shoulders/hands after welding using shade number 8.

The study shows that 48.5% of all the respondents had varied problems after welding using shade number 9. They include the respondents who suffered from: painful/itchy eyes (1.9%); pain at shoulders/hands (1.9%); headache and painful/itchy eyes (18.5%); painful/itchy eyes and pain at the shoulders/hands (4.9%); headache, pain/itchy eyes and face burn (5.8%); headache, painful/itchy eyes and pain at shoulders/hands (14.5%); and headache, painful/itchy eyes, pain at

shoulders/hands and face burn (1.0%). The respondents who reported that they had no problem after welding using shade number 9 were 11.7%.

According to the study, 17.4% of all the respondents had problems after welding using shade number 11. They constitute the welders who used shade number 11 and suffered from pain at shoulders/hands (15.5%) and the welders who used shade number 11 and suffered from headache, painful/itchy eyes and pain at shoulders/hands (1.9%) as shown in Figure 2. The welders who had no problem after welding using shade number 11 represents 15.5% of all the welders.

Further, 1.0% of all the welders as per the study suffered from pain at shoulders/hands, while 2.9% of the respondents had no problem after welding using shade number 12. This therefore shows that increase in shade number lead to reduced problems among arc welders after welding in the informal sector.

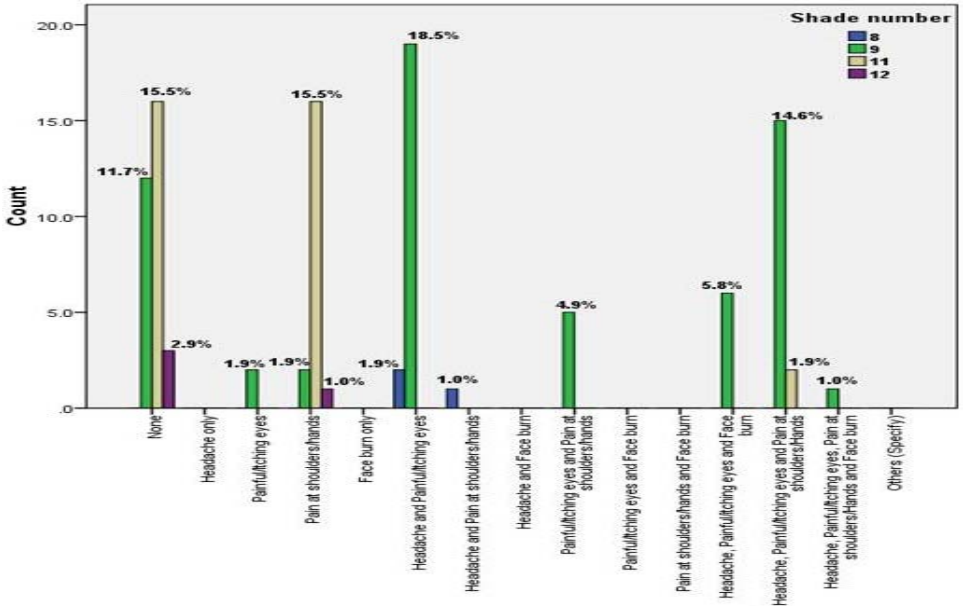

Figure 2: Problems welders experienced after arc welding

3.4 Shade Number of the PPE Used and Respondent's Education Level

The effectiveness of the UV light PPE used was seen to be influenced by the highest level of education attained by the arc welders ($p < 0.05$). The study shows that 65.7% of the arc welders who had tertiary level of education used a shade number above the minimum value, while 78.1% of the arc welders who had primary level of education as the highest education level used a shade number below the minimum value as shown in Table 3. The significant statistical relationship observed may be attributed to:

The knowledge that individuals acquire as they advance in the academic ladder.

Most (53.6%) of the Owners had tertiary level of education as shown in Table 4 hence they could weld at their convenience with no dead line to meet and they can choose what to weld.

Table 3: Shade number against level of education

Highest Level of Education		Shade Number				
		8	9	11	12	**Total**
Primary	n	0	25	5	2	32
	%	78.1		21.9		100.0
Secondary	n	0	28	7	1	36
	%	77.8		22.2		100.0
Tertiary	n	3	9	22	1	35
	%	34.3		65.7		100.0

Table 4: Education level against relationship with workplace

Highest Education Level	**Relationship with workplace**			
	Staff		Owner	
	n	%	n	%
Primary	26	34.7	6	21.4
Secondary	29	38.6	7	25.0
Tertiary	20	26.7	15	53.6
Total	75	100.0	28	100.0

3.5 Shade Number of the PPE Used and Age of the Respondent

The likelihood of finding an older arc welder using PPE with the minimum shade number filter plate was higher compared to that of a younger arc welder ($p < 0.05$). Table 5 shows that 88.0% of the arc welders aged 50 years and above used shade number above the minimum value while 88.0% of the arc welders aged 18-29 years used shade number below the minimum value. The strong relationship observed between age group and shade number may be due to:

Influx of varied goggles in the market which the young generation believed they suit arc welding where else the old generation held a contrary opinion.

The level of education amongst the arc welding class since majority (62.5%) of the respondents aged 50 years and above had tertiary level of education, while 59.4% of respondents aged 18-29 years had primary education as the highest education level attained as per Table 6.

The number of years the arc welder had worked as arc welder in the informal sector since all the respondents aged 50 years and above had worked for over 10 years, while all the respondents aged 18-29 year had worked for less than 11 years as shown in Table 7.

Table 5: Age of respondent against PPE shade number

Age of respondent		Shade number				Total
		8	9	11	12	
<18	n	0	1	0	0	1
	%	100.0		0.0		100.0
18-29	n	0	28	4	0	32
	%	88.0		12.0		100.0
30-39	n	0	18	5	0	23
	%	78.0		22.0		100.0
40-49	n	2	14	14	1	31
	%	52.0		48.0		100.0
≥50	n	1	1	11	3	16
	%	12.0		88.0		100.0

Table 6: Level of education against age of the respondent

Highest level of education	Age of respondent									
	<18		18-29		30-39		40-49		≥50	
	n	%	n	%	n	%	n	%	n	%
Primary	1	100.0	19	59.4	2	8.7	7	22.6	3	18.8
Secondary	0	0.0	11	34.4	16	69.6	6	19.3	3	18.8
Tertiary	0	0.0	2	6.2	5	21.7	18	58.1	10	62.5
Total	1	100.0	32	100.0	23	100.0	31	100.0	16	100.0

Table 7: Experience against age of the respondent

Experience	Age of respondent in years									
	<18		18-29		30-39		40-49		≥50	
	n	%	n	%	n	%	n	%	n	%
1-5	1	100.0	26	81.2	14	60.8	1	3.2	0	0.0
6-10	0	0.0	6	18.8	7	30.4	15	48.4	0	0.0
11-15	0	0.0	0	0.0	1	4.4	6	19.4	3	18.8
16-20	0	0.0	0	0.0	1	4.4	6	19.4	4	25.0
>20	0	0.0	0	0.0	0	0.0	3	9.6	9	56.2
Total	1	100.0	32	100.0	23	100.0	31	100.0	16	100.0

3.6 Shade Number and Number of Years the Respondent had worked as Arc Welder

The effectiveness of the UV light PPE used was positively influenced by the number of years the respondent had worked as a welder in the informal sector ($p < 0.05$). The study found out that the percentage of welders who used effective UV light PPE increased from 9.5% for the welders who had worked for 1-5 years to 75.0% for the welders who had worked for over 20 years as shown in Table 8. This therefore

confirms the assumption prior made that, the number of years worked increases the likelihood of a welder using an effective UV light PPE.

Table 8: Number of years worked against shade number of the UV light PPE used

No. of years worked		PPE Shade Number				Total
		8	9	11	12	
1-5	n	0	38	4	0	42
		38		4		
	%	90.5		9.5		100.0
6-10	n	0	20	7	1	28
		20		8		
	%	71.4		28.6		100.0
11-15	n	1	2	6	1	10
		3		7		
	%	30.0		70.0		100.0
16-20	n	1	0	10	0	11
		1		10		
	%	9.0		91.0		100.0
>20	n	1	2	7	2	12
		3		9		
	%	25.0		75.0		100.0

3.7 Participants' recommended UV Light PPE

According to the study, the recommended UV light PPE for arc welding, namely the hand-held welding shield and the welding helmet fitted with an appropriate filter plate are not effective for arc welding in the informal sector. Figure 3 below shows that none of the respondents recommended the hand-held welding shield or the welding helmet for arc welding in the informal sector, 18.4% recommended arc welding goggles with appropriate filter (had no design specifications in mind), while majority (81.6%) recommended others (i.e. improvised goggles designed for informal sector arc welding by the users).

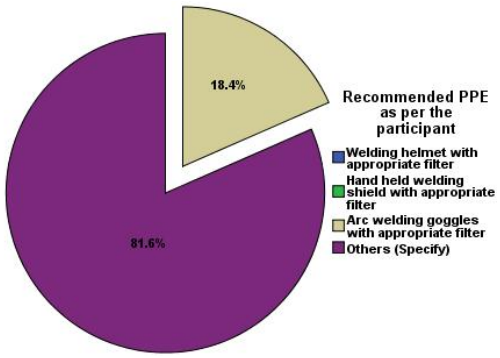

Figure 3: Recommended PPE as per the Participants

The main design specification given for the filter plate for the improvised goggles is a filter plate which is partially dark and partially clear as shown in Figure 4. The

reasoning behind the design concept was that the welder can view through the clear section when setting work and view through the dark section when welding. The dark filter plate used in the improvised goggles should be scientifically determined as one which filters the harmful UV light as per the respondents. These improvised goggles shall give the welder the protection needed as well as welding at convenience. The improvised goggles will not need one hand to be freed but the welder will nod at will all along the welding process.

Figure 4: Improvised goggles view plate

4.0 Conclusion and Recommendation

Majority of the welders used UV light PPE which are not effective in protecting their eyes during arc welding. The problems welders experienced during and after arc welding were dependent on the shade number of the PPE used. The recommended UV light PPE for arc welding namely the hand-held welding shield and the welding helmet fitted with an appropriate filter plate do not suit arc welding in the informal sector. Improvised goggles, whose filter plates are half clear and half dark best suits arc welding in the informal sector.

The study recommends that arc welders in the informal sector be sensitized on the benefits of using effective UV light PPE to protect eyes during arc welding. They are also encouraged to abide by the provisions of the lense selection guide. Further, designers of various arc welding PPE should closely collaborate with the users so as to come up with acceptable PPE for the users.

Acknowledgement

The authors would like to thank all arc welders in Machakos Town, the management of Masaku Jua Kali Association, KIE management – Machakos Branch, the District Development Officer – Machakos District, Mr. Tom and Mr. Edwin of the Chemistry laboratory, JKUAT for their cooperation during data collection.

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