TT for protection against thermal hazards EN 407-2004

Akshay Katyal and **Dr Nandan Kumar** have discussed and compared multiple variants of gloves (seamless and cut and sewn) made up of para-aramid and other blended inherent flame-retardant fibres for protection against thermal hazards as per EN 407-2004.

Our hands are most likely to receive high heat flux as compared to any other body parts during handling of hot/warm objects in any industry. The skin in the hand area is split into three main layers:

- Epidermis is the outermost layer of skin having both living and dead cells and not containing any blood vessels. This layer protects tissues from ultraviolet radiation and extreme heat exposures. Any damage to this layer due to heat exposure is called 'first degree or superficial burn' which is temporary and healing time is quick with little to no risk of permanent damage;
- Dermis layer is thicker than epidermis and is held together by a protein, Collagen. This layer contains blood vessels, sweat glands, nerves and hair follicles. Any damage to this layer of skin due to heat exposure is referred to as 'second degree or partial thickness burn' which involves irreversible damage to the epidermis and dermal tissue and are typically characterised by blisters, severe pain, reddening, and swelling of that region. This may also cause damage to hair follicles, sweat glands, or the circulatory system. The recovery time could be 10 to 20 days and medical treatment such as skin grafting may also be required;
- Subcutaneous is base of the skin and consists of connective tissue and fat. This also contains major blood vessels and nerves and any damage to this layer of skin due to heat exposure is referred to as a 'third degree or full thickness burn'. Owing to the destruction of blood vessels, both the epidermis and the dermis layers, this is the worst of three burns. In this case, spontaneous healing is not possible and skin grafts can be used to repair any damaged skin.

Protective gloves are used to reduce the effect of heat flux on our hands while handling hot/warm objects, however it's important to identify the hazards and risk assessment which should be carried out to select most appropriate type of gloves as using wrong type of safety equipments can further lead to injury. E.g. light weight cotton or polyester gloves used for protection against heat may cause burns or blisters.

In this paper, we have discussed and compared multiple variants of gloves (seamless and cut & sewn) made up of para-aramid and other blended inherent flame-retardant fibres for protection against thermal hazards as per EN 407-2004[1]. This part of the paper concerns comparing both 'seamless' and 'cut & sewn' gloves having multiple layers to achieve higher contact, convective, radiant and protection against small splashes of molten metals whilst the subsequent part of the paper will discuss protection against large splashes of molten metals such as aluminium, iron, copper and bronze. The EN 407:2004 standard specifies requirements and test methods for protective gloves that provide protection against heat and/or fire. The numbers given in the pictogram (Figure 1) indicate the gloves performance for

Table 1: Parameters as per EN 407:2004

	Test	Results measured in:	Level			
			1	2	3	4
1	After-burn time	Seconds	≤ 20	≤ 10	≤ 3	≤ 2
1	After-glow time	Seconds	Infinite	≤ 120	≤ 25	≤ 5
2	Contact heat	Temperature in °C after 15 seconds	100°	250°	350°	500°
3	Convective heat	Seconds	≤ 4	≤ 7	≤ 10	≤18
4	Radiant heat	Seconds	≤ 5	≤ 30	≤ 90	≤ 150
5	Drops of molten metal (small splashes)	Number of drops	≥ 5	≥ 15	≥ 25	≥ 35
6	Molten metal (large splashes)	Gram	30	60	120	200

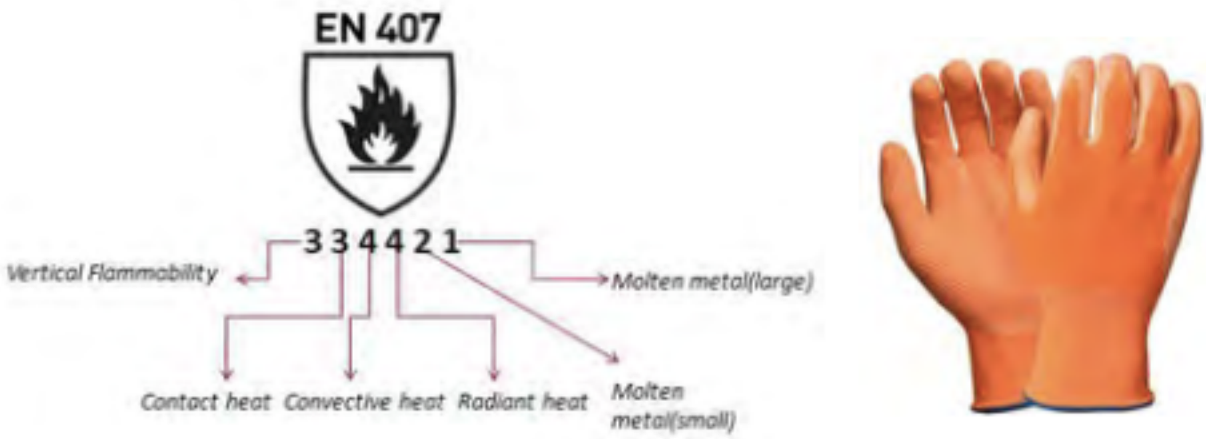

Figure 1: Pictogram shows the rating and symbols used in gloves to depict the EN 407:2004 level

each test in the standard. The higher number the better performance level. This is further segregated into various subcategories as explained below:

- Resistance to flammability [2]: In this test the glove sample is exposed vertically to direct flame for 15 seconds. After flame is distinguished the glow or burn time is measured. The lesser the after flame/glow time better the performance rating of the glove (Table 1);
- Contact heat resistance [2]: In this test the glove palm samples are exposed to temperatures between 100 degree Celsius to 500 degree Celsius in the form of heated plates, the rise in temperature by 10 degree Celsius is measured on the opposite side of the sample to determine the performance rating which is called as 'threshold time'. The glove sample needs to withstand the increasing temperature of maximum 10 degree Celsius for minimum 10 seconds to pass a certain level (Table 1);
- Convective heat resistance [2]: The inner part of the glove sample is exposed to direct flame on various parts to determine the increase in temperature by 24 degree Celsius. This test is only done if Level 3 is achieved on the flammability test;
- Radiant heat resistance[2]: This tests the back of the glove to ensure materials can resist extreme heat radiating through the glove and like the convective heat resistance test, the goal is to assess how long it takes the inners temperatures to rise by 24 degree Celsius;
- Resistance to small splashes of molten metal [2]: This test is done to assess the risk associated with hand protection while handling small amount of molten metals (e.g. iron in this case). Small drops of metals are also generated while welding joints using heat or pressure. Electrode/Gas, Tungsten insert gas (TIG), metal insert gas (MIG), micron plasma, brazing and manual arc welding (MMA) are few examples of welding techniques used in the industry. It has been observed that spatters mostly adhere to gloves/ sleeves, causing charring or hole formation or even ignition to the clothing. The performance of glove sample is measured on the number of drops needed to raise the temperature by 40 degree Celsius on the opposite side of the sample (Table 1);
- Resistance to large splashes of molten metal [2]: Simulated skin is affixed to the inside of the sample

Table 2: Gloves specification sheet

Glove Type	Composition	Gloves Weight/ Pair(g)	Yarn Count (Ne)	GSM
Gauge 7 + cotton liner	100% p-Aramid (cotton gloves inside)	290	16/2	850
Gauge 7 with terry loops	100% P-Aramid	65	16/2	510
Gauge 13 (leather on palm)	100% P-Aramid	50	16/2	325
Gauge 7+cotton liner	60% m-Aramid & 40% wool (cotton gloves inside)	250	10/2	650
Cut & stitched	P-Aramid+ stainless steel wire	300	10/2	750

Figure 2: Multiple variants of heat protective gloves (seamless, cut & stitched)

glove. Molten metal is then poured over the glove to determine what quantity will damage the simulated skin. If molten metal droplets remain stuck to the glove or if the glove ignites, the sample will fail with zero score. The weight of molten metal decides the rating for this parameter (Table 1).

Materials and methods

Inherent flame-retardant (IFR) fibres such as para-aramid (1.7 dtex, 51 mm) and meta-aramid (1.7 dtex, 51 mm), were used in the development of HPT Aracore® gloves. In the current paper, we have focussed mainly on para-aramid and meta-aramid based seamless and cut & stitched gloves and the subsequent part of this paper would cover other IFR blended fibres reinforced with stainless steel and other multi-fibre filament materials to achieve protection against heat as well as cut/slash/lacerations.

Knitted Seamless gloves using HPT Aracore® yarns: Various brands of para-aramid and meta-aramid yarns are available in the market, e.g. Twaron®, Kevlar®, Heracron®, Teijin®, Technora®, Taekwang®, Arawin®, Taparan®, X-fiper® etc which provide protection against thermal hazards. 'Meta' and 'Para' refers to the location of chemical bonds present in the chemical structure of aramid. Owning to the para position, chemical bonds of para-aramid fibres are more aligned as compared to meta-aramid which are in zigzag pattern resulting in lower tensile strength as compared to para-aramid fibres. Technically, para-aramid fibre is poly para-phenylene terephthalamide (PPD-1) and the monomers used to manufacture para-aramid are 1,4-phenyl-diamine (para-phenylenediamine) and terephthaloyl chloride in an n-methyl pyrrolidone solvent, para-aramid fibres are in yellow colour [3 ,4]. The chemical name of meta-aramid is poly meta-phenylene isophthalamide and is manufactured using meta-phenylene diamine and isophthaloyl dichloride, meta-aramid fibres are ecru/off-white in colour. Aramids

Table 2: Gloves specification sheet

Test Parameters		Unit	Results	Level achieved
Gauge 7	Vertical Flammability		No after flame, afterglow, melting, dripping observed	4
	Contact Heat	Seconds	15 at 350°C & 12 at 500°C	3
	Convective Heat	Seconds	36	4
	Radiant Heat	Seconds	58	3
Gauge 7 Terry	Vertical Flammability		No after flame, afterglow, melting, dripping observed	4
	Contact Heat	Seconds	9 at 250°C & 36 at 100°C	1
	Convective Heat	Seconds	6	2
	Radiant Heat	Seconds	25	2
Gauge 13 stitched with leather on palm	Vertical Flammability	-	No after flame, afterglow, melting, dripping observed	4
	Contact Heat	Seconds	10 at 250°C & 52 at 100°C	1
	Convective Heat	Seconds	20	4
	Radiant Heat	Seconds	64	3

contain amide links that are hydrophilic in nature and are resistant to many organic solvents and salts. HPT Aracore® yarns [5] are manufactured using aramid fibres and are used in this study to knit 7 gauge, 10 gauge and 13 gauge glove liners. Further, comparative study was performed with leather stitched on the palm side of the gloves as shown in figure 2. A range of seamless knitted gloves were also knitted using meta-aramid fibres blended with dyed blue wool (60/40) on gauge 7 knitting machine (Figure 2). Table 2 shows detailed specification of gloves used for this study.

Cut and stitched gloves using specialized HPT Aracore® knitted fabrics: HPT Aracore® yarns reinforced with stainless steel (50 micron) were used to manufacture 12-gauge circular knitted fabric which further layered with p-aramid based terry knitted fabric (7 gauge) to manufacture cut & stitched gloves. A needled punch layer (250 GSM) of m-aramid blended with p-aramid (60/40) was also used as an inner layer to provide comfort, dexterity and extra protection from heat, flame as well as against small splashes of molten metal (Figure 2).

Results and discussions

The aramid based seamless knitted gloves are mostly used for protection against thermal hazards especially where dexterity is required. Owing to high tensile strength of aramid fibres alongwith their ability to withstand tensile stress, abrasion and chemicals at high temperatures of upto 400°C, these fibres are preferred for hand protection against thermal hazards. Table 3,4 & 5 show that HPT Aracore® based seamless and cut & sewn gloves achieved level 4 in the vertical flammability test, this is mainly due to presence of aramid fibres which are inherent flame retardant in nature. The 7 gauge seamless p-aramid gloves with cotton liner achieved contact heat level 3 due to presence of cotton gloves as the inner layer. Few ideal applications of these two plied seamless gloves are glass and stainless-steel handling, tyre manufacturing, removing products from the autoclaves, demoulding thermoplastics, etc. Both 7 gauge terry and 13 gauge seamless gloves achieved contact heat level 1 due to lighter weight of liners, i.e. 65 gram and 50 gram respectively, however due to presence of leather on the palm area, the 13 gauge para-aramid liner performed better at 100 degree Celsius.

Table 4 shows that seamless gloves knitted using meta-aramid/wool blended yarns with cotton as inner liner achieved contact heat of level 3 which was equivalent to that of 7 gauge para-aramid gloves with cotton as inner liner. Due to better abrasion resistance of para-aramid (and less fibrillation) than meta-aramid fibres, seamless gloves of para-aramid fibres are mostly used for hand protection. Further, meta-aramid/wool blended gloves achieved level 3 for protection against small splashes of molten metal test (Table 4). The cut & stitched gloves were manufactured using multilayers of HPT Aracore® yarns where para-aramid fibres were reinforced with stainless steel wire in core. Further, a needlepunched nonwoven (p-aramid/modacrylic) was used as a middle layer.

Table 3,4 & 5 show that cut & stitched gloves achieved contact heat of level 3 as well as better protection against convective and radiant heat as compared to para-aramid and meta-aramid 7 gauge seamless gloves. Further, due to presence of three-layered structure, these gloves achieved level 4 for protection against small splashes of molten metal. The cut & stitched gloves are thick and less dexterous as compared to seamless gloves; hence, these gloves are suitable for foundry die casting, hot steel metal handling, glass installation, press and stamping applications.

Conclusions

HPT Aracore® yarns are used to manufacture seamless and cut & stitched gloves for protection against thermal hazards. The seamless gloves were plied using cotton gloves as inner layer to further improve contact heat performance. In order to achieve dexterity and for handling of smaller hot objects such as jewelry manufacturing or automotive assembling, terry/loop structure is more suitable for seamless aramid gloves. The leather reinforcement on the palm side provides protection against puncture along with higher abrasion resistance. Further, aramid yarns were reinforced with stainless steel to secure higher cut performance. Para-aramid based gloves are preferred over meta-aramid due to better abrasion resistance and less fibrillation of para-aramid fibres. The multilayered cut and stitched

Table 4: EN 407 test standards for seamless meta-aramid/wool blended gloves

Test Parameters	Unit	Test Results	Level achieved
Vertical Flammability	-	No after flame, afterglow, melting, dripping observed	4
Contact Heat	Seconds	16 at 350°C	3
Convective Heat	Seconds	33	4
Radiant Heat	Seconds	54	3
Small splashes of molten metal	No. of drops	After 26 drops temperature reached more than 40°C	3

Table 5: EN 407 test standards for Cut & Stitched gloves

Cut & stitched gloves			
EN407 Test Parameters	Unit	Test Results	Level achieved
Vertical Flammability	-	No after flame, afterglow, melting, dripping observed	4
Contact Heat	Seconds	18	3
Convective Heat	Seconds	43	4
Radiant Heat	Seconds	60	3
Small splashes of molten metal	No. of drops	35	4

gloves are more suitable for protection against small splashes of molten metals as compared to seamless knitted gloves. Further work is required to design and develop protective gloves suitable for protection against large splashes of motel metals.

References

1. Althorpe, H., "Handling Extreme Temperatures" in Health and Safety International Journal, November 2016 Edition.
2. PrEN 407:2004 Technical Committee CEN/TC 162 "Protective clothing including hand and arm protection and lifejackets", February 2004.
3. Sinclair., R., Textiles & Fashion (Materials, Design & Technology), Woodhead Publications, 2015.
4. Jassal, M., & Ghosh, S., Aramid Fibres- an overview. Indian Journal of Fibre and Textile Research, 27. 290-306, 2002.
5. Katyal, A., & Kumar, N. Innovative textiles for protection against mechanical hazards EN-388-2016, Asian Textile Journal, August 2019 Edition.
6. Kevlar Aramid Fibres, 2019, DuPont, https://www.dupont.com/brands/kevlar.html. ITJ

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