Enhancing Stab Testing Standards: Investigating the Influence of Angle of Incidence on Stabbing Performances of Different Protective Textiles

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Background

For the last few decades, an increased number of attacks using knives-sharpened instruments, screwdrivers, and syringes has been widely reported throughout the world, including the US (Nayak et al., 2017). Among these threats, cut, spike, and puncture are considered the most difficult due to their ability to cause continuous damage through cutting edges during stabbing. This type of threat poses a significant risk to vulnerable and first responders including law enforcement officers, police officers, correctional officers, bodyguards, etc. To address such threats, various researchers have worked on developing stab-resistant clothing made of different materials including 2D (Xuhong et al., 2012), 3D(Li et al., 2021) (Li et al., 2025)(Abtew et al., 2021)(Abtew et al., 2020), UD(Crouch, 2019) fabrics made of high-performance fibers, coated with thermoplastics (Kim & Nam, 2012) and laminate composites (Hou et al., 2013). Besides, researchers have explored the uses of nanomaterials including, carbon nanotubes (CNT), silica nanoparticles (SiO2), and shear thickening fluids to enhance the anti-stabbing properties of textile fabric(Obradović et al., 2017)(Gong et al., 2014). The stab resistance capabilities of these materials are typically evaluated through various methods, including the commonly used and worldwide accepted standards, National Institute of Justice (NIJ Standard–0115.00-USA) (Rice et al., 2000) or Home Office Scientific Development Branch (HOSBD Body Armour Standards for UK Police(Croft & Longhurst, 2007). According to these standard protocols, the stab performances of the materials may be influenced by various parameters including type of materials, type of knife used, striking energy, and testing conditions. However, despite the importance of considering various parameters, those standards only recommended two types of angles of incidence, 0 and 45°, to assess the performances of the materials. However, to the best of the authors' knowledge, no research has investigated how different angles of incidence affect the stab performances of the protective textiles (Fig 1(a)). The objective of the current research is to bring a new stab testing protocol and investigate the effects of the different angles of incidence on the stab performance of protective textiles.

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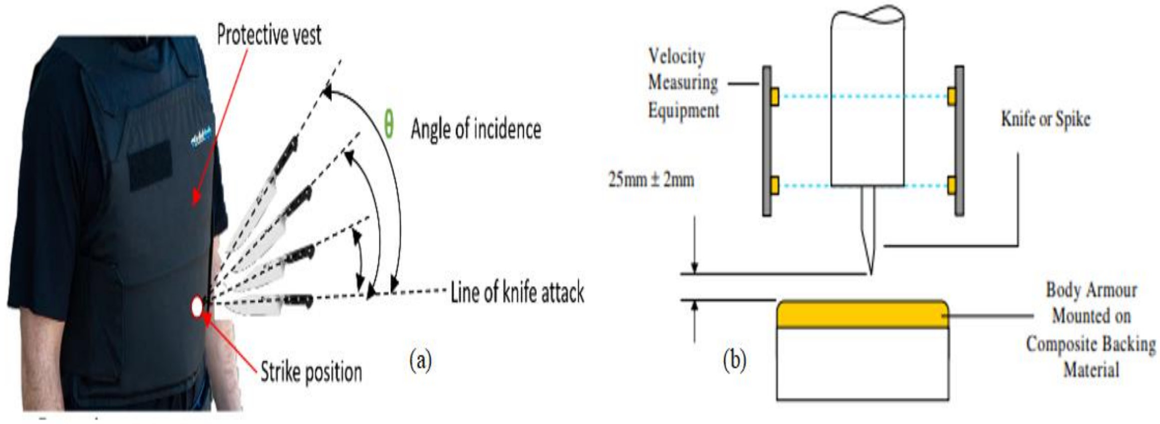

Fig. 1. (a) Different angle of incidence during stabbing of the protective vest and (b) Schematic views of stabbing test apparatus for a knife

Materials and Experimental Method

To investigate the effect of the angle of incident, an orthogonal layer-to-layer (O-L) 3D woven fabric (F1) made with 5 weft layers, a 930 dTex p-aramid yarn and 25 twists/m yarn twist and having a 970gm/m^2 linear area density was designed and manufactured. Besides, a 2D fabric (2D) by Teijin Aramid made of similar yarn and composition with the developed 3D fabrics was also used in the study for comparison. Specimens with 100 mm x 100 mm^2 areal dimensions were prepared from each fabric type. The drop tower impact test system, working under the principle of falling of knife at a specified height with its weight influence (gravity) to generate energy for impact was customized to accommodate different angles of incidence for HOSBD based stabbing test (Fig. 1(b)). The test was carried out at different angles of incidence (0°, 22.5°, 45° and 67.5°). However, the result for 67.5° was omitted and not included in the analysis due to the instability of the specimen on the backing material during the test. After the strike, the deformation at the back of each tested specimen was printed using an RTV 181 polycondensation silicone. The printed silicone was 3D scanned and precisely measured using Design Concept software to quantify the stabbing performance of each specimen based on the Depth of Trauma (DOT), Depth of Penetration (DOP), and Length of Penetration (LOP).

Results and discussion

During a perpendicular (0°) impact, the DOP is measured from penetration of the knife through the rear face of the specimen, while the DOT is the distance from the top surface of the specimen to the start of the penetration. However, angled strikes (θ) result in two different trauma depths on either side of the impact: a shorter depth and a longer depth. As shown in Fig. 2(a), for a 0° angle of incidence, both the 2D and 3D woven protective fabric specimens exhibit a similar trend, wherein the DOT increases as the angle of incidence rises from 0 to 45°. On the contrary, the DOP is minimal at 22.5° compared to 0° and 45° for both protective textile specimens. However, the 3D woven fabric, F1, demonstrates higher DOP values and lower values of DOT as the angle of incidence increases as compared to the 2D woven fabric specimen. Such difference is due to the increased pore size within the 3D woven fabric, which becomes more exposed and susceptible to easy penetration by the knife at higher striking angles. Besides, the LOP represents the total slant

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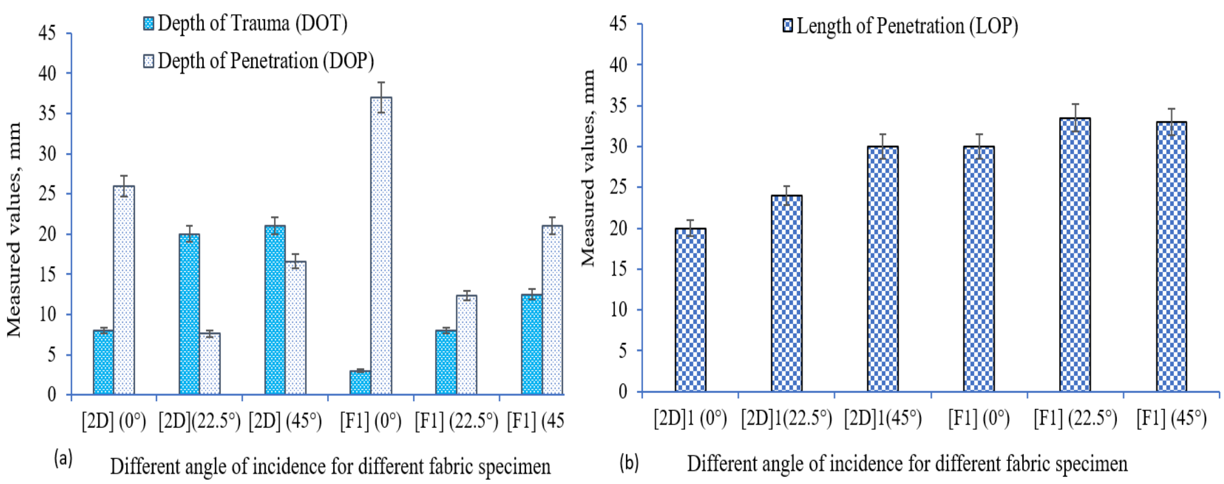
length of penetration along the edge line of the knife. Fig. 2(b), reveals that the LOP exhibits higher values as the angle of incidence increases for both protective textile structures. This suggests that textile structures experience increased penetration depth with higher angles of incidence, potentially compromising their stab resistance capabilities.

Fig. 2 (a) The maximum Depth of Trauma (DOP) and Depth of Penetration (DOP) and (b) the



maximum Length of Penetration (LOP) along the knife edge while tested specimens made of different fabric structures with specific angles of incidences ([0°], [22.5°] and [45°]).

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Final remarks

The investigation aimed to provide valuable insights into how different angles of incidence affect the stabbing performance of protective textiles. Such findings will not only contribute to a deeper understanding of material behavior under dynamic loading but also inform researchers, armor developers, manufacturers, and testing standard setters to consider the various angles of incidence during engineering, developing, and testing evaluations of stab protective textiles.

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References

Abtew, M. A., Boussu, F., & Bruniaux, P. (2021). Dynamic impact protective body armour: A comprehensive appraisal on panel engineering design and its prospective materials. *Defence Technology*, *17*(6), 2027–2049. https://doi.org/10.1016/j.dt.2021.03.016

Abtew, M. A., Boussu, F., Bruniaux, P., Loghin, C., & Cristian, I. (2020). Enhancing the Ballistic Performances of 3D Warp Interlock Fabric Through Internal Structure as New Material for Seamless Female Soft Body Armor Development. *Applied Sciences*, *10*(4873), 1–19.

Croft, J., & Longhurst, D. (2007). HOSDB Body Armour Standards for UK Police (2007) Part 2: Ballistic Resistance. In *Crown Copyright* (Issue 39).

Crouch, I. G. (2019). Body armour – New materials, new systems. *Defence Technology*, *15*(3), 241–253. https://doi.org/10.1016/j.dt.2019.02.002

Gong, X., Xu, Y., Zhu, W., Xuan, S., Jiang, W., & Jiang, W. (2014). Study of the knife stab and puncture-resistant performance for shear thickening fluid enhanced fabric. *Journal of Composite Materials*, *48*(6), 641–657. https://doi.org/10.1177/0021998313476525

Hou, L., Sun, B., & Gu, B. (2013). An analytical model for predicting stab resistance of flexible woven composites. *Applied Composite Materials*, *20*(4), 569–585. https://doi.org/10.1007/s10443-012-9289-0

Kim, H., & Nam, I. (2012). Stab Resisting Behavior of Polymeric Resin Reinforced p-Aramid Fabrics. *Journal of Applied Polymer Science*, *123*, 2733–2742. https://doi.org/10.1002/app

Li, M., Abtew, M. A., Chen, X., & Boussu, F. (2025). Stabbing and ballistic resistances of the predeformed multiply three-dimensional interlock fabrics. *Advanced Structural Textile Composites Forming*, 495–526. https://doi.org/10.1016/B978-0-443-21578-0.00020-2

Li, M., Wang, P., Boussu, F., & Soulat, D. (2021). Investigation of impact performance of 3-dimensional interlock polymer fabrics in double and multi-angle pass stabbing. *Materials and Design*, *206*, 109775. https://doi.org/10.1016/j.matdes.2021.109775

Nayak, R., Crouch, I., Kanesalingam, S., Ding, J., Tan, P., Lee, B., Miao, M., Ganga, D., & Wang, L. (2017). Body armor for stab and spike protection , Part 1 : Scientific literature review. *Textile Research Journal*, *0*(00), 1–21. https://doi.org/10.1177/0040517517690623

Obradović, V., Stojanović, D. B., Jokić, B., Zrilić, M., Radojević, V., Uskoković, P. S., & Aleksić, R. (2017). Nanomechanical and anti-stabbing properties of Kolon fabric composites reinforced with hybrid nanoparticles. *Composites Part B: Engineering*, *108*, 143–152. https://doi.org/10.1016/j.compositesb.2016.09.095

Rice, K., Higgins, K. M., & Boyd, D. G. (2000). *U.S. Department of Justice (2000), Stab Resistance of Personal Body Armor NIJ Standard–0115.00, National Institute of Justice*.

Xuhong, M., Xiangyong, K., & Gaoming, J. (2012). The experimental research on the stab resistance of warp-knitted spacer fabric. *Journal of Industrial Textiles*, *43*(2), 281–301. https://doi.org/10.1177/1528083712464256

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