

Multifunctional design of footwear for hot environment condition

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Abstract. For some time design of a new product is not connected only with aesthetic, artistic appearance but moreover with functionality and engineering (from rightful selection of materials, construction, and technological concept to prototyping). One good example of this is design of multifunctional footwear as well as hiking footwear, footwear for soldiers, police officers, first responders etc. All mentioned kinds of footwear have lot of specific requirements to fulfil starting from maintaining and enhancing mobility to maximizing protection and eliminating or minimizing the risk for the wearer. Therefore, designing appropriate footwear represents a great challenge not only for designers but for engineers as well. Having that entire in mind few years ago, Faculty of Textile Technology University of Zagreb started the research with the aim to develop 21st century multifunctional footwear for e.g. military, police, first respondents or any special human forces for different weather environment. The paper presents how it was done in the case of boots for hot environment conditions

1. Introduction

Footwear that protect human feet against harsh conditions such as cold and/or wet environments, and hard and rough ground surfaces are known for thousands of year (Figure 1 [1-3]). Through their history, they passed a lot of changes in design, used materials and production but all in order to fulfil end-users requirements ranging from fashion to comfort and protection. That is why today a lot of subtypes of footwear, each with its specific characteristics, exist on the market e.g. sport shoes, trekking/hiking shoes, summer shoes, protective shoes, working shoes etc. One of such particular footwear is footwear for soldiers, police officers, first responders etc., which can be used in different and extreme environment condition (cold or hot environment).

Many reports have documented that extreme weather rather than the enemy have defeated armies. Lessons learned from previous wars such as the Korean War, the two World Wars and the Gulf War have demonstrated that the soldiers' performance is largely determined by the performance of footwear [4]. Military footwear have lot of specific requirements to fulfil starting from maintaining and enhancing mobility to maximizing protection and eliminating or minimizing the risk for the



wearer (protection against ballistics; battery acid; degradation by sea water, human sweat, or microbiological agents; falling heavy objects; flames or heat; insects and snake bites; nuclear and chemical threats; etc). Therefore, designing appropriate military footwear represents a great challenge not only for designers but for engineers as well.



Figure 1. History of footwear.

Today, in each new product development, considerable efforts should be put in designing process from rightful selection of materials, construction, and technological concept to prototyping and consumer desires (Figure 2) [5]. Only in that case new product will be designed and functionalized according to the end user needs and requirements.

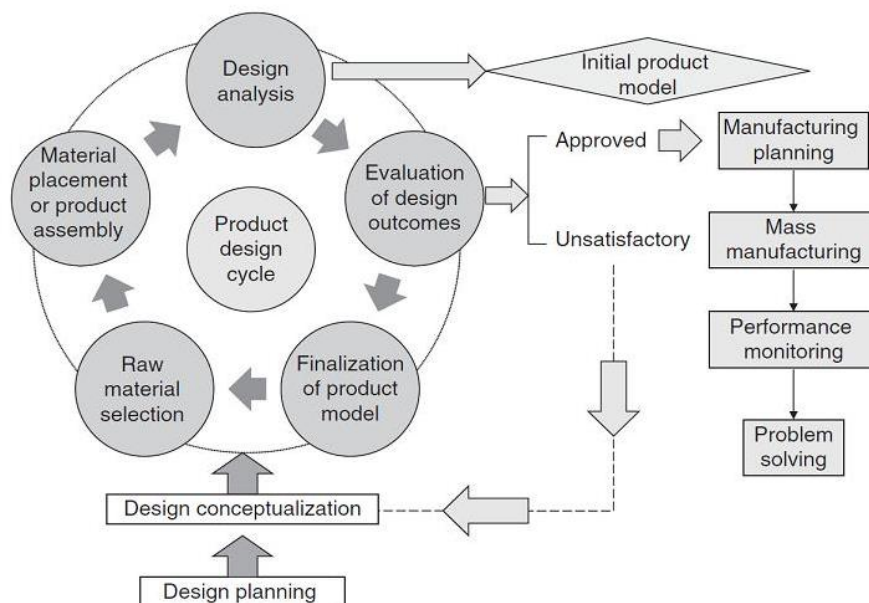


Figure 2. Product design concept.

The process of designing of specific products (for example protective clothing or footwear) includes the entire design activity for the development of new products with high technological content from the initial idea and first project concept to the feasibility analysis, considering new materials and researchers during designing, prototyping and manufacturing. Designing of specific products means balancing between design requirements and function, performance, protection and comfort [6]. In this paper through multifunctional design, development and production of boots for hot climate condition will be presented.

2. Experimental part

21st century has put many requests on engineers when designing new products and most of them have the same prefix – multifunctionality. Having in mind that footwear for soldiers, which is designed to provide support for the ankle, allow walking on a variety of terrains, and to protect the feet from a variety of environmental situations share those characteristics with hiking boots, rain and snow boots, and safety boots. Few years ago, we started the research with the aim to develop multifunctional footwear for e.g. military, police, first respondents or any special human forces for different weather environment.

In line with common product design cycle (Figure 2), design analysis, raw materials selection, way of product assembly, evaluation of design outcomes, prototyping, testing prototype in real environment, and corrections of prototype were done according to the end-user recommendations and suggestions. As a result of such integrated and iterative process of product development new multifunctional boots for hot weather conditions are developed.

3. Results

According to a survey on functionality, ergonomics, comfort, protection, shape, weight etc. conducted among end-users basic design sketch of new multifunctional boots was done (Figure 3).



Figure 3. Sketch of multifunctional boots for hot environment condition.

Based on proposed model, available materials and technology construction parts of new boots (36 of them) are defined (Figure 4). Since there are so many different parts in one boot it was very important to choose right material that will fulfil all end-users requirements regarding resistance on abrasion, tearing, perforation, penetration, bending, motor fuels etc., while at the same time assuring proper comfort for wearer in harsh hot environment. In addition, materials for all 36 parts for new boots should be at the same time capable to be combined together assuring esthetical and functional value as well as comfort.

In production of new boots high quality waterproof leather, multilayered textile materials, three-layer laminate with a waterproof breathable membrane and combination of PU/rubber were used (Table 1). Upper material was cow leather and multilayered textile materials (PA, cotton and PES). Cow leather should be waterproof, with thickness 2.1 to 2.3 mm so that it can satisfy parameters,

which are connected with breaking strength and load. These parameters have influence on quality, strength, elasticity and plasticity during manufacturing process and on final product – boots. Also according to ecological standards, chromium content shall not be detected. Other parameters (water permeability, water absorption, water vapour permeability) are connected with comfort of boots for hot environment condition. For multilayered textile materials are important thickness and mass per unit area, so the boots can be lighter. Tear resistance and breaking strength are important in usage regarding the durability of boots. For lining materials three-layer laminate with a waterproof and breathable membrane (1st layer 80% PA / 20% PES; 2nd layer PTFE membrane; 3rd layer 100% PA) was used. Sole was profiled, made in combination of PU/rubber since it should be tear, bending and motor fuels resistant.



Figure 4. Structural parts of multifunctional boots for hot environment condition.

During technological process of boots manufacturing, it is very important to bring together all parts of boots from different materials in final product, which will be functional, aesthetic and satisfy all conditions of use (protection and comfort). Seams at the socks lining should be welded with special band at the specific temperature to ensure water resistance of the boots. Socks lining and upper part of boots should be slipped on the mould and connected with the main sole using glue. In this process few different types of adhesives can be used - special type of granulate, neoprene adhesive and two-component PU adhesive.

Table 1. Specification of materials used in boot production.

| Tested parameter | Requirements |
|---|--------------------------------------|
| Characteristics of the leather | |
| Type of leather | waterproof cow leather |
| Thickness (mm) / (HRN EN ISO 2589) | 2.1 – 2.3 |
| Breaking strength (N/mm ²) / (HRN EN ISO 3376) | ≥ 15 |
| Breaking load - two sided notch (N) / (HRN EN ISO 3377-2) | ≥ 120 |
| pH value / (HRN EN ISO 4045) | ≥ 3.2 |
| Chromium content (VI), (mg/kg) / (HRN EN ISO 20344) | Cr (VI) shall not be detected (< 10) |
| Water permeability (g) / (HRN EN ISO 20344) (HRN EN ISO 5403) | ≤ 0.2 g after 60 minutes |
| Water absorption (%) / (HRN EN ISO 20344) (HRN EN ISO 5403) | ≤ 30 % after 60 minutes |
| Water vapor permeability (mg/(cm ² h)) / (HRN EN ISO 20344) | ≥ 0.8 |
| Coefficient of water vapour (mg/cm ²) / (HRN EN ISO 20344) | ≥ 15 |
| Characteristics of the multilayered textile material (1 st layer: 100 % PA; 2 nd layer: 100 % cotton) | |
| Thickness (mm) / (HRN EN ISO 5084) | ≥ 0.8 |
| Mass per unit area (g/m ²) / (HRN ISO 3801; HRN EN 12127) | 450 - 490 |
| Breaking strength (N) / (HRN EN ISO 13934-1) | lengthwise 70 widthwise 50 |
| Tear resistance at 100 000 cycles: weight loss (mg) / (HRN EN ISO 12947-3) | 0 (no losses) |
| Tear resistance (number of cycles, without hole) / (HRN EN ISO 20344) | wet > 25600 dry > 12800 |
| Water vapour permeability (mg/cm ² h) / (HRN EN ISO 20344) | ≥ 2.0 |
| Coefficient of water vapour (mg/cm ²) / HRN EN ISO 20344) | ≥ 20 |
| Characteristics of the three-layered laminated material (1 st layer: 80% PA / 20% PES; 2 nd layer: waterproof and vapour permeable membrane based on PTFE; 3 rd layer: 100% PA) | |
| Thickness (mm) / (HRN EN ISO 5084) | 0.5 – 0.8 |
| Mass per unit area (g/m ²) / (HRN ISO 3801; HRN EN 12127) | 220 – 260 |
| Waterproofness (Pa) / (HRN EN 20811) | > 20000 |
| Breaking strength (N) / (HRN EN ISO 13934-1) | lengthwise ≥ 330 widthwise ≥ 650 |
| Tear resistance at 100 000 cycles: weight loss (mg) / (HRN EN ISO 12947-3) | 0 (no losses) |
| Tear resistance (number of cycles, without hole) / (HRN EN ISO 20344) | wet ≥ 25600 dry ≥ 12800 |
| Water vapour permeability (mg/cm ² h) / (HRN EN ISO 20344) | 18 |
| Coefficient of water vapour (mg/cm ²) / HRN EN ISO 20344) | 150 |

According to the specified materials and available production processes in cooperative partner industry boots prototype were done and given to the volunteers (soldiers and members of the mountain rescue service as first responders) for real field testing in hot environment. From nearly all of them the feedback was positive meaning that all their requests and expectations are fulfilled, although some of them suggested that size of the boots might be better adjusted to the foot type (narrow; wide; types of arch). Based on such results final form of multifunctional boots for hot weather conditions (Figure 5) was placed in the commercial production. Today they are standard equipment for rescue operations during summer time and they are very comfortable and durable hiking footwear.



Figure 5. Multifunctional footwear for hot weather conditions.

4. Conclusion

Commercialization of idea, in this case footwear for hot weather conditions intended for usage in demanding situation proved to be possible through multifunctional design of new product performed by interdisciplinary teamwork of engineers and designers according to the end-users' requirements and suggestions. Today, ever increasing requirements are put on footwear quality, durability and endurance of multifunctional footwear in use, but also on maximum comfort and safety of the user. All of these requirements asks for the usage of top quality leather and high performance materials that offer water and steam impermeability.

References

- [1] Ravilious K 2010 *World's Oldest Leather Shoe Found—Stunningly Preserved* (National Geographic News) <http://news.nationalgeographic.com/news/2010/06/100609-worlds-oldest-leather-shoe-armenia-science/>
- [2] Choklat A 2012 *Footwear Design* (London: Laurence King Publishing Ltd) p 10
- [3] A history of shoes (The Victoria and Albert Museum) <http://www.vam.ac.uk/shoestimeline/>
- [4] Luximon A 2013 *Handbook of footwear design* (Philadelphia: Woodhead Publishing) p 318
- [5] El Mogahzy Y E 2009 *Engineering textiles* (Cambridge: Woodhead Publishing Limited) p 68
- [6] Dammaco G et al 2012 Design of Protective Clothing *Functional Protective Textiles*, ed S Bischof Vukušić (Zagreb: University of Zagreb Faculty of Textile Technology), chapter 1 pp 1-32