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Examination of Waterproof Pockets as Protective Carriers for Smart Garments

Akıllı Giysilerde Koruyucu Kılıf Olarak Su Geçirmez Ceplerin İncelenmesi

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EXAMINATION OF WATERPROOF POCKETS AS PROTECTIVE CARRIERS FOR SMART GARMENTS

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ABSTRACT: The importance of smart garments is increasing day by day for entertainment, sports, medical and military fields. Both hard electronics and textile based soft electronics find application in these areas. In our previous study, we focused on crew loss detection system that was applicable for team sports such as sailing. We designed a two pieces electronic system in which a master system was fixed on the boat and a slave system was implemented in the sailing garments. This study brought a new requirement; the need of a waterproof case that would protect the electronic slave system from sea water in case the sailors fall overboard. As a result of this need, in this study, we have designed and tested waterproof pockets that could serve as waterproof carriers for the slave system of sailing garments. For this purpose, studies were carried out using two different approaches. In the first approach, 15 types of pockets were developed by using three different fabric materials and 5 different seam sealing techniques. These pocket prototypes were tested by exposing them to the water for 12 h. In the second approach, an electronic circuit was developed by using a humidity sensor to test the pocket samples those were immersed to water. According to the results of the first approach, samples containing polyester base fabric, polyurethane and polyester membrane and double-sided sealing tape gave the best results. By converting the best pocket design into a garment sleeve, the humidity sensor containing test apparatus was tested and measurements were taken successfully from the system.

Keywords: Waterproof pocket, seam sealing, electronic circuit, humidity sensor, smart sailing garment

AKILLI GİYSİLERDE KORUYUCU KILIF OLARAK SU GEÇİRMEZ CEPLERİN İNCELENMESİ

ÖZ: Eğlence, spor, tıp ve askeri alanlarda akıllı giysilerin önemi her geçen gün artmaktadır. Hem klasik elektronik devreler hem de tekstil esaslı elektronik devreler bu alanlarda uygulama bulmaktadır. Bir önceki çalışmamızda, yelkencilik gibi takım sporları için uygun olan mürettebat kayıp tespit sistemine odaklanılmıştır. Bu kapsamda, tekneye ana sistemin sabitlendiği ve yelken giysilerinde uydu sistemlerinin yer aldığı iki parçalı bir elektronik sistem tasarlanmıştır. Bu çalışma yeni bir gereksinimi beraberinde getirmiş, denizcilerin denize düşmesi durumunda elektronik uydu sistemini deniz suyundan koruyacak su geçirmez bir taşıyıcıya ihtiyaç duyulmuştur. Bu ihtiyacın bir sonucu olarak bu çalışmada, yelken kıyafetlerindeki uydu sistem için taşıyıcı görevi görebilecek su geçirmez cepler tasarlanmış ve test edilmiştir. Bu amaçla iki farklı yaklaşım kullanılarak çalışmalar yapılmıştır. İlk yaklaşımda, üç farklı kumaş malzemesi ve 5 farklı dikiş kapama tekniği kullanılarak 15 tip cep geliştirilmiştir. Bu cep prototipleri, 12 saat boyunca suya maruz bırakılarak test edilmiştir. İkinci yaklaşımda, suya daldırılan cep numunelerini test etmek için nem sensörü içeren elektronik bir devre geliştirilmiştir. Birinci yaklaşımın sonuçlarına göre en iyi sonuçları poliester esaslı kumaş, poliüretan ve poliester membran ve çift taraflı kaynak bandı içeren numuneler vermiştir. En iyi cep tasarımı giysi koluna entegre edilerek nem sensörü içeren test aparatı ile test edilmiş ve sistemden başarı bir şekilde ölçümler alınmıştır.

Anahtar Kelimeler: Su geçirmez cep, dikiş sızdırmazlığı, elektronik devre, nem sensörü, akıllı yelken giysisi,

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1. INTRODUCTION

"Smart" or "intelligent" garments are a member of functional textiles. They can be defined as textile end-products that can sense, process and/or response to environmental stimulus or bodily changes. They can contain hard electronic components or soft textile-based electronics. Different definitions and classifications of smart garments and wearable technologies can be found in the literature. Smart garments are developed for different purposes for the fields of entertainment, security, medicine, communication, military or sports [1-3].

On the other hand, waterproof textiles belong to another group of functional textiles. They can be obtained by coating or lamination technologies, and they can serve for different end-use areas such as workwear, chemical protective garments, medical textiles, raincoats, sportswear (i.e. sailing garments, mountaineering garments), military garments etc. [4-5]. In order to maintain the waterproofness of coated and laminated fabrics along the seam lines, their seams are finished by different seam sealing techniques such as hot air welding, hot wedge welding, ultrasonic welding, adhesive bonding etc. [6-7]. In the studies which develop electronical functions for textiles that would be used in wet conditions, the function of the electronic systems should be secured by the facilities of waterproof textiles and seam sealing techniques.

In the literature, some studies can be found separately on seam sealing techniques [8-12] and smart garments [13-21]. In the studies which subject the seam sealing techniques, standard test methods are used in order to reveal the strength or waterproofness of two-dimensional seam sealed fabrics to evaluate their usage in straight seams (i.e. side seams). Within the scope of our full project, a smart sailing garment was designed. In the design, there was a loss detection system which contained a Bluetooth communication system in corporation with an Inertial Measurement Unit (IMU) sensor [22]. In order to have a successful end product, the electronic system should be secured in a waterproof structure that was a part of the sailing garment. Therefore, the electronic system could be protected from the rain or sea water in case the wearer falls in the water. For this purpose, within the scope of the current study, waterproof pockets were designed by using different kinds of laminated fabrics and seam sealing tapes/techniques. As an originality, textile-based materials were tested in the form of a three-dimensional garment segment in this study. Produced pocket samples were examined for 12 h in a water tank in order to reveal their waterproofness performance.

2. MATERIALS AND METHODS

2.1. Textile Materials

Textile-based materials of this study were laminated fabrics, a water-repellent sewing thread and seam sealing tapes (Bemis, USA). Also, an acrylic-based waterproof spray was used to enhance the water-repellent properties of sewn seams (Orapi Vertro 715). Properties of laminated fabrics are given in Table 1 while properties of seam sealing tapes are given in Table 2.

2.2. Electronic Materials

The electronic system consists of data logger and sensor boards. Data logger is equipped with LPC2148 ARM7 microcontroller, built in Li-Ion battery charger, built in micro-SD card logging memory, and installed basic analog input text data logging software [22]. The data logging software can be easily modified for different type of sensors interface. After data acquisition and logging to microSD card, it can be downloaded directly from the logging card by USB mass storage interface. The board immediately starts data logging with power on and stops with the stop button. Figure 1 shows the photo of data logger card with Li-Ion battery and sensor board. The battery is 3.7V Li-Ion battery especially suitable for the data logger card which has 3.3V regulator and battery charger circuit. 800mAh power rating serves 40 hours of battery life when 20mAH continuous operation dissipation power for both data logger and sensor board.

Table 1. Laminated fabric properties (Kara, 2017)

Sample code	Base fabric	Membrane	Unit mass (g/m^2)	Thickness (mm)	Waterproofness (cm water column)
PP-PU	Polypropylene (PP)	15 µ thick polyurethane (PU)	98	0.28	>1100
PES-PU	Polyester (PES)	15 µ thick PU	122	0.21	534
PES-PES	Polyester (PES)	20 µ thick polyester (PES)	127	0.22	537

Table 2. Properties of seam sealing tapes

Tape code	Content	Softening temperature of adhesive (°C)	Tape width (mm)	Application of tape
ST 104	Barrier: PU Adhesive: PU	98	22	Stitching + taping
ST 604	Barrier: PU Adhesive: PU	105	22	Stitching + taping
Double sided tape 3415	Barrier: PU Adhesive: PU	83	10	Double sided taping

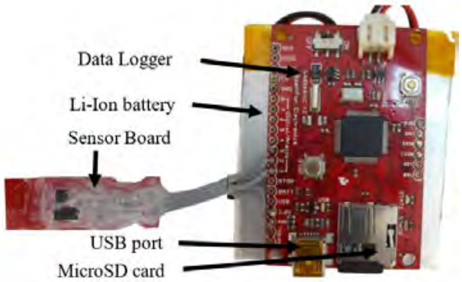

Figure 1. Data logger card with Li-Ion battery and sensor board

The sensor board includes three different analog type sensors: temperature, humidity, and wetness. The temperature sensor is well known TMP36 sensor operated in between −40°C and +125°C [23]. TMP36 output scale factor is given by 10mV/ °C, and the output voltage is 750mV at 25°C. The humidity sensor is selected as HIH-4030 has linear relative humidity output [24]. The temperature and humidity sensor were placed on the back side of the water level sensor which is formed by two closely placed conductance lines. Sufficient water amount changes the resistance value of the two different conductance lines, and this can be evaluated as wetness sensor which is an extra information for the humidity sensor data. Figure 2 shows the two sides of the sensor board as a photo.

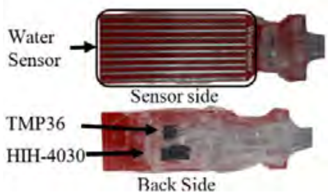

Figure 2. Sensor board sensor side and back side

As a result, data logger electronic system and the battery are covered with a waterproof plastic bag and a flat cable is used to connect the sensor boars outside of the bag. Silicone is used to protect the connection pads and the sensor metal pins from water contact. Data logging automatically starts with the power on switch, then whole system is placed into the garment that intended to be tested. The data logger system photo is given in Figure 3.

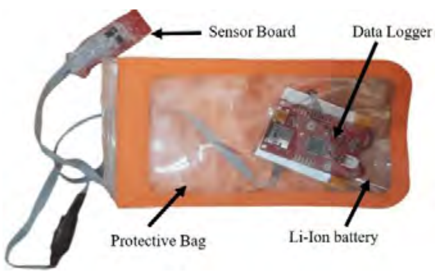

Figure 3. Protective bag, data logger and sensor board photo

3. METHODS

3.1. Production of pocket prototypes

Pocket prototypes were produced using the laminated fabrics, sewing thread, water-repellent spray and seam sealing tapes. Pocket size was designed to fit the electronic slave system that would be implemented to the sailing garment. Dimensions of the pocket prototypes are given in Figure 4.a. Pocket prototypes were produced by 5 different methods (Figure 4.b). Stitch density was kept as 3 stitches/cm and a Juki DDL-8500-7 model electronic lock stitch machine was utilized for sewing all the samples. Seam allowances were kept as 5 mm and they were sewn from the upper side after folding the seam allowance, for the initial 4 prototypes (Figure 4). As schematized in Figure 4.b, for the 1st design, the pocket prototype was only sewn with water-repellent sewing thread. In the 2nd design, it was further sprayed with the water-repellent spray. In the 3rd and 4th design, the stitches were further covered with ST 104 or ST 604 seam sealing tapes by applying heat. In the 5th design, the pocket was formed directly using the double-sided tape.

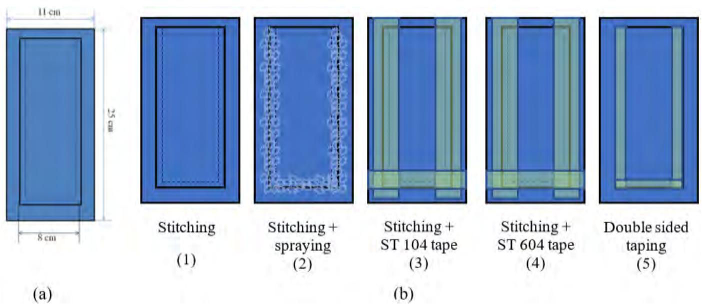

Figure 4. a) Dimensions of the pocket prototypes and b) pocket prototypes with different seam constructions

Produced samples with 3 different laminated fabrics can be seen in Figure 5. These studies were carried out in Dokuz Eylul University, Textile Engineering Department.

3.2. Examination of pocket prototypes according to the first approach

According to first testing approach, 15 pocket prototypes were examined for their waterproofness by immersing at least 10 cm of the pockets to the water tank. In order to maintain a straight sample in the water, a small load was hung to the bottom of the pocket prototype. The inner parts of the samples were checked for water leakage after 1min, 2 min, 5 min, 10 min, 30 min, 1 h, 2 h, 6 h and 12 h periods. In order to observe the leaked water at the seam edges, test papers fitting to the pockets, were prepared. After each time period, the test papers were removed and checked for leakages. A schematic of test apparatus is shown in Figure 6.a and a wetted pocket-paper pair is shown in Figure 6.b.

PP-PU samples	
PES-PU samples	
PES-PES samples	

Figure 5. Pocket prototypes with different seam constructions

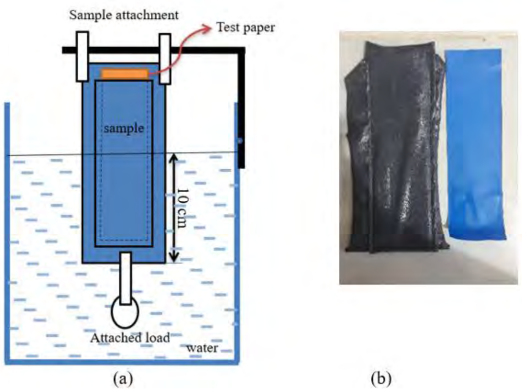

Figure 6. a) Testing of samples via first approach
b) Example of a wetted pocket and control paper

3.3. Examination of pocket prototype according to the second approach

According to second testing approach, the best performing pocket was converted to a sleeve for the targeted final sailing garment. In this design, a transparent window was opened to observe the screen of the electronic slave system. The upper part of the sleeve was secured from water leakage by using a waterproof zipper (YKK, Turkey). A waterproof channel was formed to carry the cables of the electronic system to the shoulder part of the garment. All of the parts of the sleeve assembly were covered with the appropriate sealing tape. The sleeve prototype which contains the waterproof pocket is shown in Figure 7.a. In this test procedure, the humidity sensor (Figure 7.b) was put in the pocket of the sleeve. The wires of the humidity sensor were placed in the waterproof channel and the processor and battery part was put out of the test equipment. The schematic of the test equipment is given in Figure 7.c.

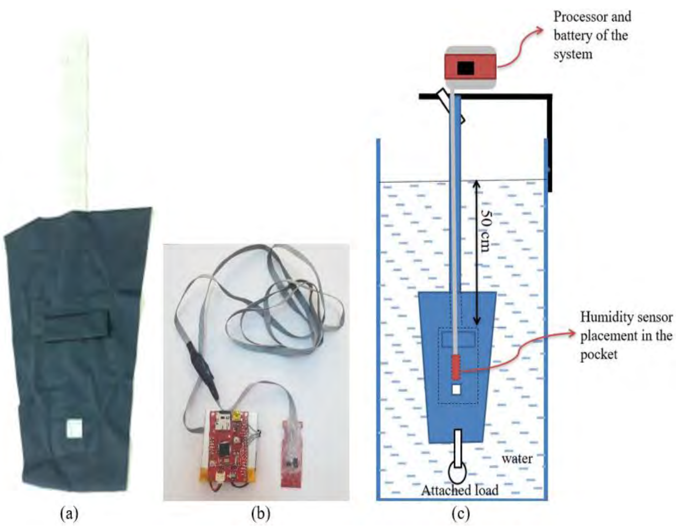

Figure 7. a) Implementation of waterproof pocket on the sleeve
b) humidity sensor and complementary electronic circuit
c) testing of samples via second approach

3.4. Data Logger Software

Data logger has a pre-installed general use software; however, the software can be modified to the user's selections. The general data logger software algorithm is given in Figure 8.

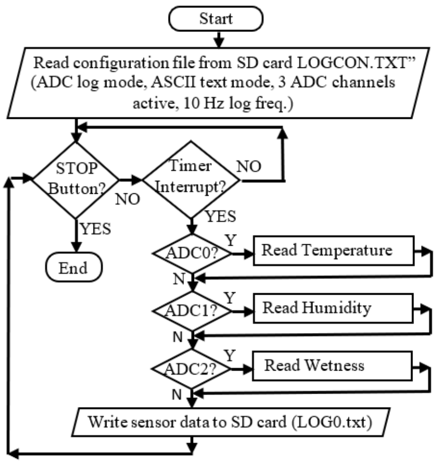

Figure 8. Data logger algorithm

After powerup from the battery, data logger awakes and checks the configuration file located in SD card attached. The primary settings are logger mode, ASCII or binary file format, logging frequency, and Analog to Digital Converter (ADC) channels enable. The data logger configured as an ADC mode logging. Here, three ADC channels are enabled to gather temperature, humidity, and wetness sensors analog data. The data recorded in an ASCII file named LOG0.txt and ASCII mode text format is sufficient to obtain three channel ADC data. Data acquiring is repeated every 0.1sec corresponding 10 Hz frequency. This is safe frequency set as stated on the data logger guide as considered the 500Hz maximum frequency limit for three ADC channels conversion [25].

3.5. Data Converter Software

Data acquisition can be achieved using two different approaches. The first approach is to find the minimum change rate of the sensor and adjust the speed of the analog to digital converter accordingly. The second approach is to convert at a high speed allowed by the analog-digital converter and to slow down the speed required for the sensor by sampling it at multiples of the conversion speed. Here, sensor data logging time interval is 0.1 seconds considering the detailed analysis of specific time regions, but usually it is generally enough to collect data in the time basis of several minutes for slow changing sensors like temperature. Therefore, using the second approach, the long duration logging data is converted into lower frequency data to ease the analysis. This converting process can be done with spreadsheet software but need to know how to make this conversion. Instead, a data converter software was written to overcome this challenge. The general data converter software algorithm is given in Figure 9. The software simply reads logged file as a text file format from SD card. User enters the required parameters as experiment start time, input file and output file conversion frequencies, and separator character that separates the data. Then, output file is created using specified parameters.

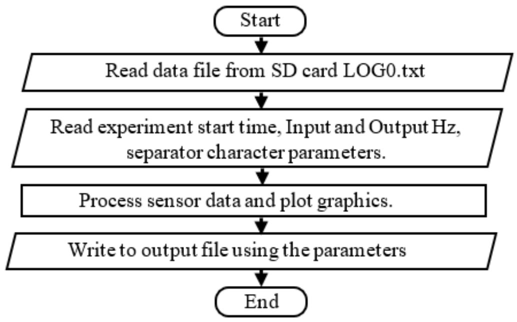

Figure 9. Data converter algorithm

The main interface screen of the logger data converter software is given in Figure 10. After the separator character, input sample frequency, output sample frequency and start time is entered to the designed input boxes, user simply presses the "convert file" button to start conversion. If user wants to see the converted data, presses "plot read data" button to see the data graphically.

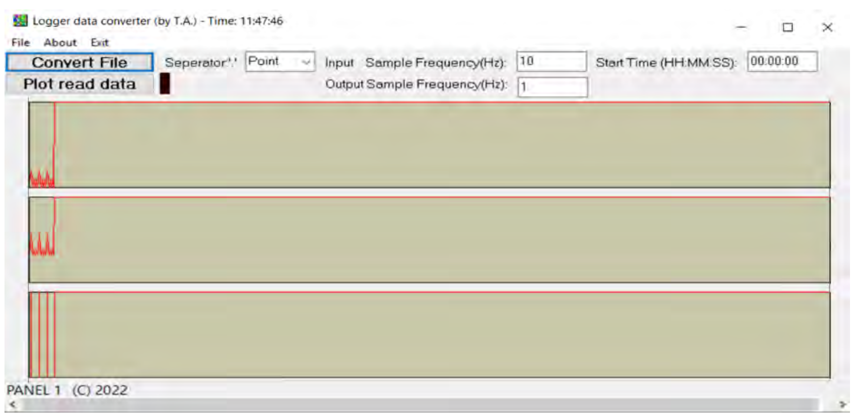

Figure 10. Logger data converter main screen.

4. RESULTS

Test results are given separately for the first and second testing approaches, in the following parts.

Water leakage results of 15 pocket prototypes are given in Table 3. These results were obtained according to the first testing approach.

According to the results, all of the -only stitched- samples exhibited leakage after the 1 min test period. Similarly, PP-PU and PES-PES pocket samples with stitching + spraying, leaked after 1 min test period. Within the sprayed samples, only the PES-PU sample remained unleaked after 2 min.

When the PP pocket samples were evaluated, only the stitching+ ST104 and stitching + ST 604 samples remained dry after 2 min test period. In general, PP pocket prototypes did not show waterproofness after 2 min test period.

According to PES-PU and PES-PES sample results, taped samples showed higher leakage times when compared to PP-PU samples. Within the all PES pocket samples, only the double-sided taped pockets remained dry even after 12 h of test period.

According to the second testing approach, data from wetness, temperature and humidity sensors were recorded in the register as 10 samples in 1 second. All sensors were powered by a cable approximately 1.5m long from the recorder and positioned inside the suit. The system has been tested with the garment prototype produced and the accuracy of the values received has been confirmed. Figure 11 shows the long-time sensor data with their time stamps. From graphical plot it is easy to see wetness level, temperature and humidity levels were stable and did not change with time. This proves that the pockets were waterproof and protected the electronic circuit inside.

Table 3. Water leakage results of pocket samples

Main group	Sub-group	1min	2min	5min	10min	30min	1h	2h	6h	12h
PP-PU	Stitching	X								
	Stitching+ spraying	X								
	Stitching+ ST 104 taping	✓	✓	X						
	Stitching+ ST 604 taping	✓	✓	X						
	Double sided taping	X								
PES-PU	Stitching	X								
	Stitching+ spraying	✓	✓	X						
	Stitching+ ST 104 taping	✓	✓	✓	✓	✓	X			
	Stitching+ ST 604 taping	✓	✓	X						
	Double sided taping	✓	✓	✓	✓	✓	✓	✓	✓	✓
PES-PES	Stitching	X								
	Stitching+ spraying	X								
	Stitching+ ST 104 taping	✓	✓	✓	X					
	Stitching+ ST 604 taping	✓	✓	✓	X					
	Double sided taping	✓	✓	✓	✓	✓	✓	✓	✓	✓

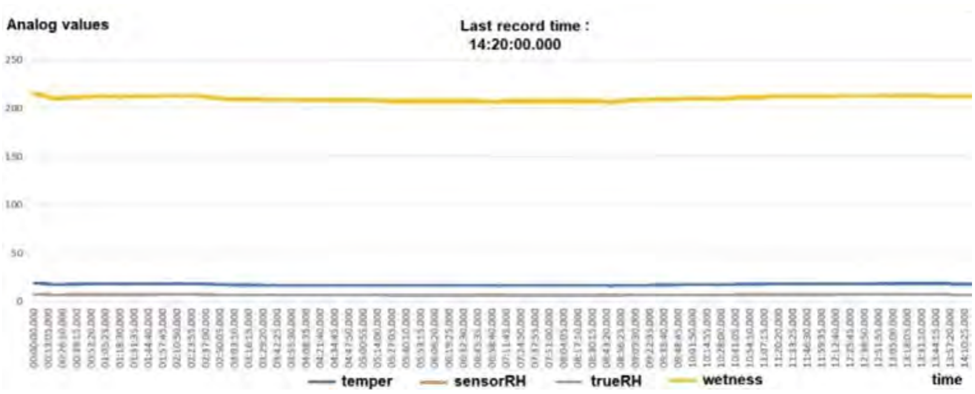

Figure 11. Long-time sensor data with their time stamps

5. DISCUSSION AND CONCLUSION

In this research, waterproof pockets were designed and produced to be implemented to a smart sailing garment. The pockets were tested against water leakage by using two testing approaches. According to the first approach, all the PP pocket samples exhibited low waterproof performance and leaked within 5 min in a water tank. This can be a result of lower heat application during the adhering process of these samples. The heat application was lower for these samples as polypropylene has low melting point. This problem can be solved by developing seam sealing tapes with lower softening points.

On the other hand, PES-PU and PES-PES samples with double-sided tapes endured against water leakage at least 12 h when immersed in water. This time could be higher if the test period was extended. Such a long waterproofness period could help to get data from the fallen sailor in case of a loss. Therefore, the health and position information could be monitored from the slave system until the sailor was rescued.

The electronic data logging makes the experimental setup automatic and easy to use without observing the system for long time. The standard 10Hz logging frequency data can be converted using the developed PC data logger converter software to lower frequency data to analyze long duration data easily. The experiment showed the waterproofness test can be easily conducted with the applied data logging system.

This study was limited by the seam sealing tapes used. Also, as this was a demonstration study to develop a test system for testing waterproof pockets, systematical welding was not realized in this study. In the further studies, the experimental design can be extended by using systematical welding conditions and the effects of welding parameters on the waterproofness of pocket prototypes can be compared.

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