STUDY AND OPTIMISATION OF SWIMMING PERFORMANCE IN SWIMSUITS DESIGNED WITH SEAMLESS TECHNOLOGY

Gianni Montagna[1], André Catarino[2], Helder Carvalho[2], Ana Maria Rocha[2]
[1] *Faculty of Architecture, Technical University of Lisbon, Department of Art and Design, Lisboa, Portugal*
[2] *University of Minho, Department of Textile Engineering, Guimarães, Portugal*
whiteman@det.uminho.pt

ABSTRACT

Hydrodynamic resistance, also called water drag, is one of the most discussed issues in swimming sport and recognized as a major factor in terms of swimming performance. Different authors tried to demonstrate that body compression is responsible for a better result in swimming, based on the fact that body modelling improves energy saving and helps to maintain the performance on repetitive movements. In this paper, different weft knitted fabrics, prepared under predefined production parameters, were tested in order to establish which were the most adequate for compressive effect and which parameters contribute most for compression.

Key Words: weft knitted fabrics, compression, sports

1. INTRODUCTION

In swimming, as in all other sports, the performance improvement in order to achieve the best results is nowadays the most important prerequisite to improve athlete's social projection and to stimulate the sports industry. Few hundredths of seconds could make the difference between gold and a silver medal and consequently could mean more or less visibility for the entire marketing machine beyond the athlete and his performance. The research on swimming has identified a group of major problems that need to be improved in order to reduce contest time and decrease swimmer fatigue and energy expenditure. Maximal swimming performance depends on the interplay between biomechanical and bio energetic aspects [1]. Since water density is approximately 800 times higher than air's (998.2 vs. 1.205 kg/m^3 at 20ºC and 760 mmHg) it requires a high energy cost [2]. As a result of a hierarchy of issues that determine the swimmer's performance, the water drag problem was recognized as one of the most complex and difficult questions to solve. Performance upgrade tools provided from the world's largest swimming commercial technical garment companies such as Speedo, Arena and Tyr, among others, through the design of a high technological garment for high performance swimming athletes, concentrated their work around the problem. With the availability of a new generation of suits that cover larger parts of the body and are made of different materials than the traditional suits, there is a potential for a drag reduction [3]

Hydrodynamic resistance, also known as drag, is a major performance issue in swimming performance. Swimmer's drag consists in three different main factors: skin friction, pressure and wave [3,4,5]. Speedo claims it is possible to reduce total drag by reducing friction drag. In addition to that, the tight fitting suit would enhance co-ordination of the swimmer while reducing pressure drag [6]. Inspection of those competition swimsuits allowed identifying the extremely high compression effect produced in the athlete's body, inclusively becoming very uncomfortable to wear. Some of the differences between the previous generation swimsuits and the ultimate generation from Speedo are the weight, the stabilizing effect on muscles, and the drag effect, significantly reduced due to adequate finishing of the knitted fabric. A study conducted with garment shorts for athletics and fitness activities, by Doan et al., demonstrated that compressive garments significantly reduce impact force of muscles on the ground by 27%

compared with traditional pants. The investigation was conducted using a costume-fit hyper-compressive garment about 15/20% smaller than athlete's measurements.[7]. Compression garments are responsible for a better blood flow and a decrease of a venous stasis, reducing blood lactate concentrations during training exercises, helping the athletes to recover more quickly from fatigue. As a result, even if compression garments are not significantly responsible for maximizing the top results of athletes, they seem to have a significant effect on the endurance of the performance on repetitive movements and in longer distances, as in athletics and swimming [8].

2. RESEARCH GOALS

The work described in this paper is part of a project that intends to provide an extensive set of tools for swimming performance evaluation and optimisation, involving the measurement of several biometric signals, movement trajectories, among others, with the purpose of improving the athlete's performance. The main objective of this particular study was to evaluate the effect of some parameters directly involved in the production of a swimsuit in compression. With this information one can proceed with the design of the swimsuit with the adequate compressive effect, since a specially designed suit covering the torso of male swimmers and containing Lycra® filaments reduces the energy demand of swimming, compared with a standard racing suit [3].

3. EXPERIMENT PLANNING

The following parameters were considered for producing the fabrics: raw material, the structure used to build the fabric and the machine parameters. As raw materials, slightly texturized nylon (since it is one of the most used materials in swimsuits), flat polypropylene (due to its hydrophobic characteristics), and bare elastane were used. The fabrics were knitted using plating technique, where the yarn that stays in the technical back was bare elastane with different linear densities. It was also decided to use three different structures - jersey, simple and double pique. The pique structures contain tuck stitches which will hopefully help to increase the compressive effect. The jersey fabric was considered in this study as a reference and also because it is the most used structure in swimsuits, training swimsuits and also on several racing swimsuits. Regarding the production parameters, the yarns were previously characterized in terms of mechanical properties and the recommended yarn input tension for each one of the three yarns used was determined. Considering a multiplying factor of 20 for the maximum tension in the knitting zone, it was decided to use 2 cN as the yarn input tension for nylon, 6 cN for polypropylene and 4.5 cN for bare elastane. Three different loop lengths were used. These were chosen based on previous tests made in order to study the feasibility of producing the fabrics on those specific conditions. Table 1 summarizes the experiments made and respective planning.

Table 1. Experiment planning.

	Yarn 1 / linear density (dTex)	Yarn 2 / linear density (dTex)	Lu (cm)	Structure
Batch 1	PA / 78	EL / 78	0.30	single pique
				jersey
				double pique
			0.28	single pique
				jersey
				double pique
			0.24	single pique
				jersey
				double pique
Batch 2	PA / 78	EL / 44	0.30	single pique
				jersey
				double pique
			0.28	single pique
				jersey
				double pique
			0.24	single pique
				jersey
				double pique
Batch 3	PP / 90	EL / 78	0.30	single pique
				jersey
				double pique
			0.28	single pique
				jersey
				double pique
			0.24	single pique
				jersey
				double pique

In table 1, yarn 1 stands for the yarn in the technical front and yarn 2 for the one at the technical back. Since plating is used, the resulting linear density is the sum of these two yarns. The machine used is a Merz seamless knitting machine, model MBS, with eight yarn feeding systems and respective cams. It is a full jacquard machine, where the needles are selected through magnetic actuators. The machine is also equipped with CONI SEP yarn storage feeders and electronic yarn tension controllers from BTSR, model HP 100. It is a 13" diameter machine and the gauge is 28. Nylon was fed using CONI SEP feeders. Both polypropylene as well as elastane were fed using BTSR electronic feeders. The knitting speed was about 0.5 m/s. As shown in table 1, the planning in each batch involved changing the loop length and the structure, maintaining the yarn. This was easily accomplished through Merz's CAD/CAM programs.

4. FORCE CHARACTERIZATION

Since the main goal was to assess the compressive effect of these fabrics, a specially modified testing rig was used. The common tensile tests are not suitable for evaluating compression (ISO 13934:1999), so it was decided to use a more adequate method, inspired by medical compression hosiery. The testing rig consists of approved tensile force equipment with modified jaws, in this case cylinders where the fabric is placed and is stretched into a specific distance between the jaws. The starting distance between jaws was 265 mm and the fabrics were first stretched to a specific distance (435 mm) . The resulting stress-strain characteristic was recorded. After that initial test, different samples were tested to evaluate their behaviour concerning fatigue for two different jaw distances: 405 and 435 mm. In this test, 10 consecutive cycles were applied to each of the samples and the hysteretic curve was recorded. These distances are related with the athlete's anthropometric measures.

5. RESULTS AND DISCUSSION

Table 2 resumes the results obtained for the tensile tests, when the sample is stretched up to 435 mm distance between jaws. There are three cells that remain with no results. This was due to the fact that the produced fabric had some faults and could result in false figures.

Table 2. Measured force when the fabric tube is stretched to 435 mm distance between jaws.

			Force (N) @ 435 mm		
Code	Raw Material	Lu (cm)	Jersey	Single Pique	Double Pique
AA	PA 78 / EL 78	0.3	35.7	170	186.6
AB		0.28	45.7	307	311.2
AC		0.24	59.3	495	486.5
BA	PA 78 / EL 44	0.3	23.3	140	137.7
BB		0.28	26	285.6	260.8
BC		0.24	34	518	489.5
CA	PP 90 / EL 78	0.3	57.7	810	862
CB		0.28	53	335.2	---
CC		0.24	81.3	---	---

Figure 1 illustrates the results presented in table 2. Codes were used in order to represent all experiments in one single picture. As a general observation, the measured force increases as the loop length decreases, excepting fabric code CA. In this situation polypropylene was fed with a yarn input tension of 10 cN, resulting in a spectacular increase in the measured force.
When considering jersey structure, one can observe a slight decrease in force when the elastane is thinner (44 dTex instead of 78 dTex). Comparing polypropylene with nylon, particularly sample codes AB with CB and AC with CC, it seems that there is an increase in force, although not very important. This is interesting since polypropylene was fed with a yarn input tension of 6 cN, whereas nylon used 2 cN. The higher value of sample CA when compared to AA and BA is due to the yarn input tension of polypropylene (10 cN). It is possible that force would increase for samples CB and CC if they were produced under the same conditions as CA.

One can observe that, as expected, pique structures provide a substantial increase in force. It is also observed that, as the loop length decreases, the measured force increases.
Comparing the results obtained for single pique, samples AA, AB and AC presents the same evolution as samples BA, BB and BC: the force increases as the loop length becomes smaller. It also seems that there is no evidence about significant differences when the raw material changed, which can be observed between sample codes AB, BB and CB. Double pique essentially presents the same behaviour as single pique, so it seems that there is no special advantage in using double pique, when compression is considered. However, this result should be considered with some caution, since the tensile properties in wale direction were not addressed in this paper. The results also show that structure and loop length seem to be the most influencing parameters on these experiments. The yarn input tension apparently does not influence significantly, excepting for case CA, but the reason was already mentioned.

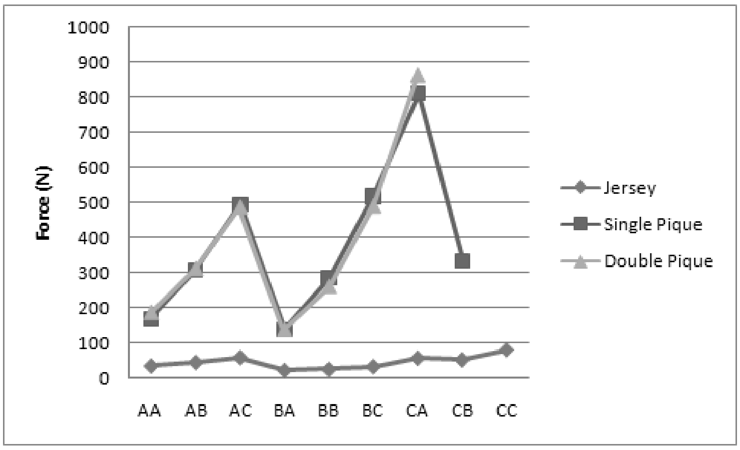

Figure 1. Measured force on fabrics at 435 mm extension.

All fabrics were submitted to cyclic tensile tests in order to better understand the effect of consecutive mechanical stress. As stated in a previous section, ten consecutive cycles were performed for two different distances between jaws: 405 mm and 435 mm. These distances correspond to the biggest perimeter on the athletes, namely 968 mm and 1020 mm. In the following images, and for clarity purposes, the fifth cycle of the experiment will be plotted. Figures 2 to 4 show the highly non-linear behaviour of these fabrics, which can be modelled by an exponential function, even for jersey structure, which shows a curve somewhat flat due to the scale used. It can be observed that single and double pique behave approximately the same way. These curves also suggest that for pique, structure has its influence until a specific loop length. Then, the latter seems to assume more importance, as single pique presents basically the same curve as double pique (figure 2, left). For some extension (20-30 mm) there is no need for a specific traction force. When relaxing, the fabrics tend to recover its initial size very slowly, even with elastane present in the structure.

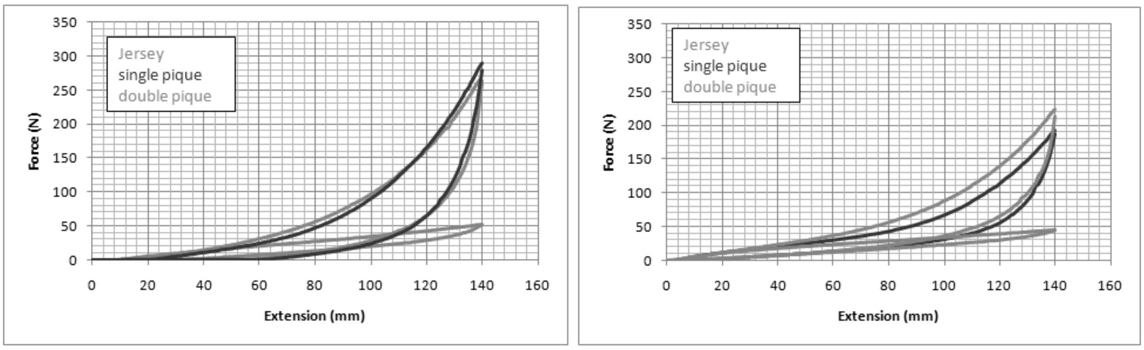

Figure 2. Cyclic tensile tests for cases AC (left) and AB (right) at 140 mm maximum extension.

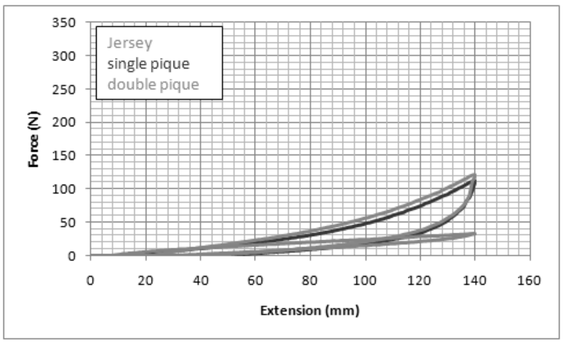

Figure 3. Cyclic tensile tests for cases AA at 140 mm maximum extension.

One of the most interesting results came from the experiment where polypropylene (case CA) was fed with a higher tension (10 cN). Even for the highest extension tested, the fabric didn't show a significant loss of capabilities concerning compressive effect. The hysteretic cycle was considerably stable, even at the end of the tenth consecutive cycle.

The results presented are quite relevant for the design a swimsuit. In the opinion of an athlete – a member of the research group - , the fabrics that resulted from pique structures and tight loop length (0.24 cm) were most similar to the racing swimsuits that are normally used, in terms of compression. The most difficult fabric to try was the one identified by case CA. That fabric has the disadvantage of being very stiff. However it is a very stable structure, which is an advantage for embedding sensors and conductors as planned in a future stage. The tensile characterisation, together with the Laplace equation, will help to preview the correct fabric dimension for the different parts of the swimsuit, which constitute the next step on this research.

6. CONCLUSIONS

This paper presents a study performed concerning weft knitted structures, with the purpose of evaluating the factors that could contribute in higher extent to the compressive effect on training and racing swimsuits, since compression is one of the most used techniques for reducing drag. Using different raw materials, structures and machine parameters, it was possible to conclude that the factors that seem to be the most important are structure and loop length. Single pique and a 0.24 cm loop length resulted in an interesting weft knitted fabric regarding compression purposes. The cyclical tensile tests showed that these fabrics have a stable although non-linear hysteretic curve that can be modelled by an exponential function and thus one can preview the fabric's most adequate dimensions in order to obtain a specific compression. This information will be very important when designing the sensor equipped swimsuit.

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7. REFERENCES

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