PHYSICAL PROPERTIES OF COMPRESSIVE KNITS COMPOUND WITH DIFFERENT MATTERS IMPREGNATED BY MICROCAPSULES MOISTURIZING

Compressive knits include a very varied group of different device functions, from the more merely (protection) to the more developed (scar improvement, skin hydration, etc.). We combined two therapy forms - the pressure and the hydration of burned skin. We essayed to reunite the advantages of two techniques pressure and hydration in only one and the same instrument in the form of compressive knit with microencapsulated surface. The compressive knits are elaborated with different textile matters such as Cotton/Spandex, Polyes-ter/Spandex, Polyamide/Spandex, Viscose/Spandex and Cotton/Polyester/ /Spandex. The hydration product chosen in this application is the jojoba oil. The microcapsules were prepared according to the phase separation method. Physical properties such us pressure, mass per area, the Thickness, air permeability and adiathermic power are tested. According to the results, we conclude that the knits are compressive, comfortable, smooth, allergen-free, thin and washable. The raw materials selected for the samples studied are biocompatible with human skin.

Keywords: microcapsules; hydration; compressive knits; physical properties.

The burning of skin is a destruction of skin cladding, that is obtained by the transfer of heat from the energy source to the skin [1]. Many techniques are introduced to face up the problem of the hypertrophic scar recovery [2,3]. The best strategy of the treatment and prevention of scars is compressive therapy.

In the late 1960s, “Silverstein”, in the military hospital of San Antonio, TX (USA), described the positive effect of the bottom vascular support on a scar caused by grave burn. Larson [4], in the center of “Burn Shriners” in Galveston, TX (USA), observed an equally positive effect similar to the use of the fabric exerted a pressure into burned scar. Linares [4] resorts to the pressure and the compressive knit to warn the scars caused by grave burns. The compressive knit is destined to avoid the appearance of hypertrophic and retractile cicatrices or get better the look. It allows avoiding the inflammation and reducing the lack of cohesiveness of inter collagen fibers. The compressive knit can be used over a few weeks to a few months [5]. It is constituted of textile, relatively rigid and very elastic, which compresses the skin layers to flatten. In fact, the compressive knit, by its stitches, breaks the Cheloïde developments of the skin. It has given excellent results, for that reason it must be prescribed in the event of deep and extend burns. The skin hydration stakes complexes mechanisms. Many constitute elements of epidermis participate. Among them, the Jojoba oil takes an essential role for skin hydration. The jojoba oil is the wax continued in the jojoba (Simmondsia chinensis) seeds, plant lives in the bushes, original of south of Arizona and the California [6]. This oil directly affects skin aging, hydrates dry skin, feeds the hair and avoids sebum accumulation. The application of jojoba oil facilitates the process of cellular new spelling and increases as elasticity as gentleness and the skin firmness. Other than its high content of ceramids, jojoba oil also contains vitamin E, which acts as an anti-

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oxidant and protects the skin against free radicals [7]. The principle of hydration product is to bring a certain quantity of hexagon water; fasten this water within the stratum corneum, control the natural movement of the water within the stratum corneum and check the evaporation of intrinsic water [7-9].

To facilitate the application of the liquid hydration product, we transform it into solid microcapsules simple to fix onto the knit surface [10-12]. In this study, we used ethyl cellulose microcapsules containing jojoba oil, obtained by phase separation method. The microcapsules were applied onto different compressive knits surface using the acrylic resin (AR) by impregnation. The distribution of microcapsules in the knit surface is characterized by scanning electron microscopy (SEM). With light pressing by the skin, the microcapsules break to liberate oils.

The treatments of skin burns by jojoba oil are [13] to cool it (in order to calm down and limit the lesion extent), reduce pain (the pain absorbs itself with water diffusion through the skin and by evaporation at the surface), stopping infection (from the burn, the skin loses its hydro fatten film, which serves as protection, making it more vulnerable for outside attack and represent a way to the bacteria), stopping dehydration (when the pain finishes, the evaporation must be stopped, or else the skin dehydrates and heals less easily) and rehydration (facilitates the healing).

**EXPERIMENTAL**

**Materials and methods**

The different samples (S1-S5, Table 1) were knitted by classic yarns with different titles and different composition on a circular knitting machine with English gauge $E = 14$.

The samples were tested according to the French norms: pressure (NF G 30 102), mass per area (NF G 07-150), thickness (NF G 07-153), air permeability (NF G 07 111) and adiathermic power (NF G 07-107).

**Preparation of ethyl cellulose microcapsules**

Ethyl cellulose microcapsules were prepared as reported in the literature [14].

Phase 1: ethyl cellulose (1 g) was dissolved in ethyl acetate (20 ml) under continuous stirring (2500 rpm). Then, 2 g of jojoba oil was added.

Phase B: sodium lauryl sulphate (1 g) was dissolved in water (150 ml). 20 ml of ethyl acetate was added under continuous stirring (2500 rpm). Next, phase A was dropped into phase B. 300 ml of water were added to the formed emulsion to extract the organic solvent. The formed microcapsules were separated, washed and dried at 40 °C.

**Fabric treatment**

The treatment process consisted on the dispersion of the microcapsules into an aqueous solution containing a dispersant agent and a fixing agent. The dispersant agent has permitted the obtaining of microcapsules dispersed around the fixing agent. Next, the textile surface was immersed many times into the aqueous solution [15,16].

Jojoba oil microcapsules were added to knits by impregnation. Samples were obtained by a 2608 TEPA foulard of 1 kW. Bath treatment for impregnation was composed of 50 g/l of microcapsules and 25 g/l of acrylic resin. Samples were thermally fixed at a temperature of 110 °C for 5 min in a WTC binder 030. The time and the temperature of the protocol were optimized [17].

**Matter used for manufacture of compressive knits**

The compressive knit must have comfort quality, with influenced pressure and humidity absorption, at neutral feeling for skin, and possibly for aesthetics. Using flexible matter is essential. The matter is choosing according to many criteria such as: biocompatibility, absorption of fluid, mechanical properties (uniformity pressure, thin, light, etc.), decontamination and sterilization [18].

The compressive fabric is made from cotton and lycra. Recently, the compressive fabric is knitted from viscose, nylon, lycra, etc., permitting better clothe and better support than the cotton [19,20].

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lycra</th>
<th>Viscose</th>
<th>Polyamide</th>
<th>Polyester</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>15</td>
<td>85</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$S_2$</td>
<td>15</td>
<td>-</td>
<td>85</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$S_3$</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>42.5</td>
<td>42.5</td>
</tr>
<tr>
<td>$S_4$</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>85</td>
<td>-</td>
</tr>
<tr>
<td>$S_5$</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>85</td>
</tr>
<tr>
<td>Count yarn (dtex)</td>
<td>44</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>
Cotton. It gives an eternal feeling of comfort. The cotton fiber is soft, hypoallergenic, and healthy for skin contact, features high air permeability, flexibility, easy surface impregnation, the adiathermic power improves with use and the resistance improves with humidity, easy to wash and tends to shrink (amelioration of compression).

Viscose. Cellulosic fiber obtained by the viscose process. Its properties are similar to those of cotton, little elastic, crumples quickly, resistance reduces the traction especially in wet, high tendency to shrink, touch and aspect attractive.

Polyester. Fibers constituting of linear macromolecules, followed by series of several ester molecules. Polyester does not resist acetone. Fort bases and acids damage polyester. The fiber of polyester has good resistance, good adiathermic power, crease, excellent dimensional stability, not absorbent the transpiration, high electrostatic charge, difficult impregnation and rough to touch.

Polyamide. Polymer containing any amid functions \(\text{C}(=\text{O})\text{–NH}^-\) resulting from the reaction between the acid and the amine functions. Polyamide fibers are sensible to humidity, not hydrophilic, thermoplastic, highly resistant to traction, light, do not shrink, have abrasion resistance, high caloric retention, tend to keep dust, and must be kept away from acetic acid.

Cotton/polyester. The use of the mixture of cotton and polyester improves the physicochemical properties of cotton and polyester.

Microencapsulation

The microcapsules with the partition are constituted by ethyl cellulose [21]. The active product is jojoba oil. The characteristics, particle sizes, encapsulation efficiency and capacity of oil load were tested. The process parameters such as the fraction of the oil phase compared with the water phase and the stirring speed were evaluated. The morphology and the shape structure of microcapsules were studied by SEM. These microcapsules were applied onto the compressive knit by impregnation method. The results were tested by SEM [22].

RESULTS AND DISCUSSION

The compressive knit

The compressive knit must be smooth, flexible and light. Problems appear if the dermis is hit and are dominated by the retraction, the hypertrophy and less of the substance. Other problems are long immobilization and complications of resuscitation. The treatment relies on carrying of compressive knit 23/24 h during more year, to ensure the permanent skin retirement and the mobilization of the joint to avoid its stiffness [23].

Compressive knits for high burns are constituted with elastic textile in all senses; exert a homogeneity compressor on the surface [5]. These fabrics take care of burns of the second and third degree, when the total surface burned is superior to 10% of the body surface, or, when the lesion seats onto hands, face, neck, flexion fold. The fabric used must be elastic and possess excellent tolerance of skin (no irritating and no allergen) to be comfortable.

The ideal properties of fabrics are: absorption of fluid, uniform presser distributed, comfort, no allergen, thin. The compression of the knit is governed by the Laplace law:

\[ Pr = \frac{T \pi r}{r} \]  

where \( Pr \) is the pressure exerted (N/m²), \( T \) the knit tension (N/m) and \( r \) the curvature ray of compress surface (m) [24].

The compression exerted also depends on the number of sets:

\[ Pr = 4630NbT/(PeL) \]  

where \( Pr \) is the pressure under the bandage (mm Hg), \( Nb \) is the number of sets, \( T \) is the bandage tension (N/m), \( Pe \) is the extremity perimeter (cm) and \( L \) is the bandage width(cm). Measurement of the pressure of the compression knit must be carried out according to the French Norm (NF G 30 102 B). The measurement method gives value results expressed in mm Hg [25]. According to the establish value, the compressive knit will be classified in one of four classes defined in Table 2 [26].

Table 2. Compression classes [26]

<table>
<thead>
<tr>
<th>Effect</th>
<th>Pressure, mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light compression</td>
<td>15-21</td>
</tr>
<tr>
<td>Light superficial action</td>
<td></td>
</tr>
<tr>
<td>Middle compression</td>
<td>23-32</td>
</tr>
<tr>
<td>Middle superficial action</td>
<td></td>
</tr>
<tr>
<td>Light deep action</td>
<td></td>
</tr>
<tr>
<td>Strong compression</td>
<td>34-46</td>
</tr>
<tr>
<td>Superficial action and in depth</td>
<td></td>
</tr>
<tr>
<td>Very strong compression</td>
<td>From 49</td>
</tr>
<tr>
<td>Strong action forte in depth</td>
<td></td>
</tr>
</tbody>
</table>

The compressive knits are kept with one swing, they are smooth in the inside for no injury of the skin. They are washable for hygiene. Moreover, the washability allows the compressive property. In fact, the knit relaxes and shrinks in the wash.
The maximum value of the pressure exerted is not precise. In theory, the pressure must be superior to 25 mm Hg to exceed the capillary pressure. Nevertheless, good clinical results have been achieved in patients treated by pressures between 5 and 15 mm Hg [27]. Many authors [26,28] are, however, applying for the pressure inferior to 15 mm Hg as necessary, especially to favor the acceleration of the scar maturation. The same authors maintain the principle “the more the pressure is raised, the better the scar maturation”. The continuous pressure superior to 40 mm Hg increases the risk of complications such as paresthesia and maceration.

Table 3 shows physical properties of five different compressive knits. The sample with viscose/lycra has the best air permeability but the high adiathermic power. A decrease of the loss of heat by the surface of the skin is able to have a positive influence on the scar metabolism [29].

The samples with cotton/lycra and polyamide/lycra have the best compressive values. The compressive therapy accelerates the scar maturation, makes the scar more still and decreases equally the hardness and the redness of scar [30,31]. The pressure exerted neutralizes the local capillary "high blood pressure" to prevent the flight of plasmatic protein through the vessels. This allowed for improvement of the oxygen exchange in the tissue and resulting the best maturation of scar [29]. Thanks to the compressive knit, there is compression of the scar during the first month after the intervention. This mechanical compression intervenes directly on the fibroblasts by renewal of collagen and the remodelage of extra cellular uterus. There is liberation and activation of metallo proteinous of uterus, enzyme which intervenes in the remodelage of the fibrous tissue. Then, there is a lack of the myo-fibroblasts, which decreases the collagen synthesis of the extra cellular uterus. After the initial strip phase, the proliferation phase is maximum at the 10th day postoperative – from 3rd to 30th day - then the maturation phase begin in the same time. The compression is, certainly weak, perhaps inferior to 10 mm Hg, but it is effective. The burn caused the decrease of blood circulation, so the shortcoming of oxygen [32-34]. The exert pressure neutralize the local capillary "hypertension" to prevent the flight of plasmatic protein through the vessels. This is allowing improving the oxygen exchange in the tissue, result better scar maturation. So, the compressive therapy accelerates effectively the scar maturation and gives the scars more flat. Ideally, the pressure must be exerted during interrupt period of 24 h by day from the closing of cut (epithelialisation) until the end of the maturation phase [35]. So, the compressive therapy decreases the hardness and the redness of scar [4,26].

**Hydration microcapsules**

The microencapsulation consists of enclosing the Jojoba oil into ethylcellulose partition with spherical shape and the microcapsules are fixed onto compressive knits. The results presented in Figure 1 show that the microcapsules have spherical shapes and the average size about 20 μm. The average size of microcapsules applied into fabric surfaces is inferior of the average diameter of fibers so that they do not modify the initial fabric touch.

The microcapsules obtained were fixed into the fabric surfaces by impregnation (Figure 2). The process allowed unitary fixation of each microcapsule, li-

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**Table 3. Physical properties of compressive knits (P is air permeability, AP is adiathermic power, Th is thickness and MA is mass per area)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Viscose/Lycra</th>
<th>Polyamide/Lycra</th>
<th>Cotton/Polyester/Lycra</th>
<th>Polyester/Lycra</th>
<th>Cotton/Lycra</th>
</tr>
</thead>
<tbody>
<tr>
<td>P / l m⁻¹ s⁻¹</td>
<td>920</td>
<td>560</td>
<td>250</td>
<td>520</td>
<td>220</td>
</tr>
<tr>
<td>AP %</td>
<td>9.2</td>
<td>9.2</td>
<td>4.5</td>
<td>7.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Th / mm</td>
<td>1.06</td>
<td>0.95</td>
<td>1.11</td>
<td>0.80</td>
<td>1.03</td>
</tr>
<tr>
<td>MA / g m⁻²</td>
<td>199</td>
<td>263</td>
<td>288</td>
<td>183</td>
<td>252</td>
</tr>
<tr>
<td>Pressure, kPa</td>
<td>183</td>
<td>358</td>
<td>226</td>
<td>170</td>
<td>456</td>
</tr>
</tbody>
</table>

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![Figure 1. Optical micrograph of microcapsules with jojoba oil (500x magnification).](image)
miting the bending mass into the fiber surface, and consequently allowing the conservation of initial knit characteristics such as the touch, the flexibility, the lightness, etc. We obtained compressive knits relatively, thinness, lights presented a good keeping compared with wear caused by rubbing and the successive washing cycles. The use of high quantity of polymeric bending presented many modifications of the mechanical properties of the knit such us the withdrawal, the air permeability, the thermal resistance and the stretched strength [36].

As a result of the microencapsulation technology, thanks to rubbing fabric on the skin, many microcapsules will liberate progressively their active product on the epidermis. There are new hydrating products which have osmotic instruction actions. One of the particularities of these products is to keep the water molecular, which allows returning all its elasticity to the skin [13]. In the same view, the compressive knits with microcapsules of jojoba oil have good effects on the burned skin [37]. In fact, the compressive knit presents many comfort quality in the influenced compression and the humidity absorption, without skin sensation, esthetic possibly. This comfort directly influences the therapy observance.

CONCLUSION

According to the physical properties of the samples used in our study, the knits are compressive, comfortable, smooth, allergen-free, thin, light and washable. The type of the knitting and the component yarns influence the compressive knit. Thanks to their composition, the compressive knits are elastic in all directions, uniform on all surfaces. The raw materials selected for the samples studied are biocompatible with human skin.
We conclude that the therapy by compressive knit in form of microencapsulated surface is a top scientific method in the treatment and the prevention of burn scars [38]. The pressure and the hydration constitute two therapeutic treatment methods suitable without important second effect [38]. The compressive therapy accelerates the scar maturation, makes the scar more still and decreases equally the hardness and the redness of the scar. The Jojoba oil hydrates the skin, facilitates the process of cells new spelling and increases the elasticity and the skin firmness.

Abbreviations

AP - Adiathermic power (%)
AR - Acrylic resin
A - Mass per area (g/m²)
P - Air permeability (l m⁻¹ s⁻¹)
Pr - Pressure exerted (N/m²)
Th - Thickness (mm)
SEM - Scanning electron microscopy

Symbols

E - English gauge
L - Bandage width (cm)
Nb - Number of sets
r - Curvature ray of compress surface (cm)
Pe - Extremity perimeter (cm)
T - Knit tension (N/m)

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FIZIČKA SVOJSTVA KOMPRESIVNIH PLETIVA SASTAVLJENIH OD RAZLIČITIH MATERIJALA IMPREGNISANIH MIKROKAPSULAMA ZA VLAŽENJE


Ključne reči: mikrokapsule; hidratacija; kompresivna pletiva; fizička svojstva.