Varstiff, an innovative variable stiffness material, applied in a Wheelchair Positioning Device.

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Abstract

Varstiff is a technology that allows a sheet material to switch from flexible to rigid state and vice versa by adjusting vacuum level through a pump. We used this Varstiff as base technology to design a Wheelchair Positioning Device. Main function of this device is to correctly position a stroke patient when seated in a wheelchair during hospital stay. Correct sitting posture supports motor rehabilitation and improves comfort and pain condition. We have shown in a preliminary study with one representative patient that during normal procedures caregivers could reduce the needed amount of manual repositionings of the patient by 50% during a week of use. The device was rated as comfortable and easily usable by the caregiver while the patient rated it as improving pain complaints.

1 Introduction

Varstiff is an innovative technology that provides sheet-like material of adjustable rigidity/flexibility through adjusting pressure, developed and patented by Tecnalia [1,2]. Varstiff consists of a laminate of engineered layers surrounded by a flexible impermeable chamber containing a valve. The main characteristic of the material is that its stiffness can be adapted through adjusting the pressure in the chamber. This creates the possibility to make shell-like rigid body fitting elements that are adapted to the actual body shape, such as a limb or the trunk, they are fitting to, as they can be shaped when flexible and used as rigid fitting element when rigidified through applying a vacuum. This is supposed to be useful for orthotic and immobilization products, among others; earlier we presented the use of Varstiff to connect rehabilitation robots to human limbs [3]. This paper describes the application of Varstiff in a Wheelchair Positioning Device (WPD) for post stroke patients. This device was developed, designed and validated in a clinic in accordance with a user-involved design process. First Varstiff properties are presented, followed by the design of the WPD and the validation with one stroke patient during normal care procedure inside a rehabilitation clinic.

2 Methods

In this section we describe the most important general properties of Varstiff, the design of the WPD, and finally the method of validation.

2.1 Varstiff technology

Varstiff is a general material concept that allows modifying the stiffness of a laminate of layers by (de-) compressing them in an airtight bag, through varying the vacuum pressure. This function depends mainly on the properties of the separate layers in the laminate, which need to be sufficiently rigid (inextensible) and have the right friction properties (high friction, but low tack). Achieved stiffness of a compressed composite depends on material properties (modulus and surface friction), layer composition and thickness, number of layers and vacuum pressure. For the functioning of Varstiff, we present two main claims [3]:

Varstiff Claim 1: Varstiff becomes more rigid with increasing vacuum

A lower pressure inside the hermetic bag leads to a higher compression force on the laminate, and this increases the stiffness. Figure 1 demonstrates this for varying levels of vacuum by showing stress strain curves for one specific implementation of Varstiff (PVC coated Dacron). The bending modulus calculated over the blue region in Figure 1, as function of varying pressure is shown in Figure 2. This behaviour generally applies.

Varstiff Claim 2: The more Varstiff layers the higher the stiffness

The bending stiffness of a Varstiff sample or product depends on total thickness and relative stiffness (bending modulus) of the Varstiff laminate. As already shown in Figure 2, adding layers reduces the relative stiffness or bending modulus, but still the increase of laminate thickness leads to an increase of net material stiffness (characterized by Figure 3).

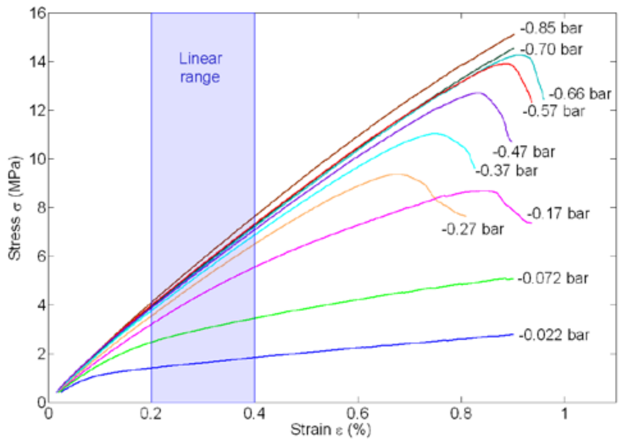

Figure 1: Stress-strain curves for Varstiff under varying vacuum levels [3]. The stiffness is characterized by the slope of the curve in the blue area, also called the bending modulus of the material, see Figure 2.

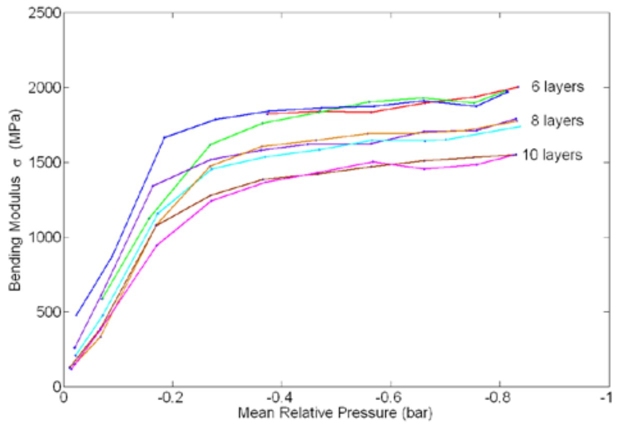

Figure 2: Bending modulus as a function of pressure and number of layers [3]. The bending modulus stabilizes around -0.4 bar, although the strength of the material can increase for higher vacuum levels. Increasing number of layers reduces the relative stiffness of a Varstiff laminate.

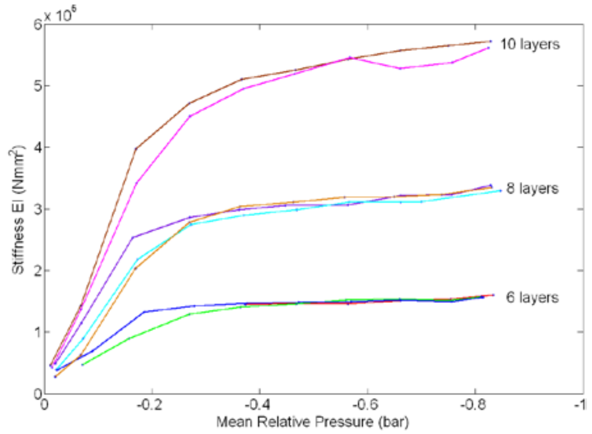

Figure 3: Sample stiffness as a function of pressure and number of layers. The increase of stiffness is caused by the increase of total laminate thickness and not by an increase of relative stiffness, as shown in Figure 2.

2.2 Wheelchair positioning device

In an iterative user involved design process we designed a Varstiff-based device to assure correct wheelchair sitting posture for sub-acute stroke subjects that stay in a hospital during this phase. During the acute and sub-acute phases after stroke, proper positioning of the patient is considered of paramount importance. Upright positioning like sitting or standing is shown to be beneficial on a number of aspects. For the sub-acute phase the main benefits of upright positioning, are related to supporting muscle tone and promoting motor system recovery [4], where control of trunk posture while sitting is considered to be the first step in motor rehabilitation [5]. Additionally, for practical reasons, during the sub-acute institutional phase, often wheelchairs are used for mobility. When patients spend a considerable amount of time per day in a wheelchair, it is important that patients are able to use the wheelchair without adverse effects, such as pain and comfort problems. The features currently considered in sitting in a wheelchair can be summarized as follows:

- In a rehabilitation hospital, where patients stay full-time during the sub-acute stage, the following methods and products are typically being used to assure safe and correct sitting during wheelchair use:
- Manual repositioning by nurses, based on observation of posture
- Restraints, such as belts, mainly to prevent falling out of wheelchair
- Specifically designed cushions and pillows, for example a “pommel cushion”, to correct sitting posture
- Table mounted on wheelchair that supports the arms
- Specific backward-tilting wheelchairs [6].

In the Gorliz hospital, participating in this project, the common method is to have nurses reposition patients when needed. Additionally a (transparent) table was used in the wheelchair in order to better position the arms and shoulders. Belt-type restraints are used when needed for safety. Main problem with this way of working is that it is very time consuming to (re-)position the patient, especially with severe stroke patients.

In order to improve this practice, we developed a new type of positioning device for use in a basic wheelchair, intended for sub-acute stroke patients. The main goal of this device is to reduce the needed number of repositionings (and thus nursing time) per patient, while achieving and maintaining a safe, comfortable and rehabilitation-supporting sitting posture. The device should not completely block the movement of the patient, but leave some space for trunk movement, both for comfort and to challenge the patient to train proper positioning by using their own remaining trunk control.

The result of the design process is shown in Figure 4. The design includes the Varstiff main shape, consisting of a wheelchair seat cushion with two “arms” that are positioned and bent around the patient in order to maintain the trunk posture, containing 9 layers of Varstiff material to provide the Varstiff functionality and a pommel cushion in order to maintain the legs positions. On top of the Varstiff piece, a “vest” is added, made of soft foam, with the function to provide visual and comfortable elements to the design. The WPD is used in combination with an arm-supporting transparent table (Figure 4).

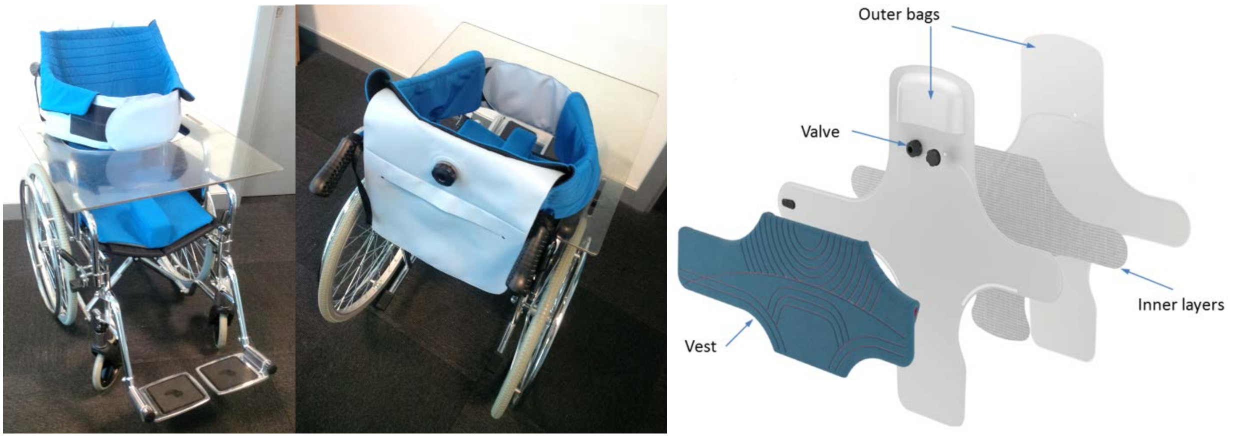

Figure 4: Final design of the Wheelchair Positioning Device. Left: clearly visible are the “arms” that support the trunk, the pommel cushion to separate the legs, and the blue “comfort vest”. Right: the white bag contains the Varstiff material, and is operated through the black valve placed at the back.

The procedure of operating the device is:

- Connect the WPD to the wheelchair with straps
- Help the patient sit down in the wheelchair equipped with WPD
- Attach the supportive table when needed
- Shape the device (in flexible state) to the size and shape of the patient
- With the vacuum pump, provide a vacuum through the back valve
- Provide the normal activities to the patient
- Reposition the patient in case of a poor sitting posture
- Re-apply the vacuum and shaping when needed, by opening and closing the valve.

2.3 Validation method

For validation of the design, we used the prototype of the WPD inside a rehabilitation hospital, during regular care for a post-acute stroke subject, that most of the day was seated in a wheelchair. We compared the times the patient-user had to be repositioned by a caregiver, comparing five half days of the normal procedure with five half days during a week using of the WPD. Furthermore we interviewed the patient-user and the nurse on the comfort, pain-effects and usability of the device.

3 Results

In the validation of the designed WPD, we selected a male stroke patient of 64 years that had problems maintaining a correct sitting posture when seated in a wheelchair. This person had a BMI of 23.4. During one week of care, this person needed to be repositioned according the observation and decision of the caregiver for 40 times, during 5 half days (alternating morning and afternoon). While using the WPD, the same person, during the same time, had to be repositioned by a caregiver 19 times. This caregiver rated the device for this patient as 2/10 (1 – very comfortable; 10 – very uncomfortable). Trunk pain and shoulder pain were scored 3/10 and 2/10 while using the WPD, while scored 5/10 and 4/10 while not

using the WPD (0 – without pain; 10 – unsupportable pain). General ease of use was rated as 4 out of 5 by the caregiver (1 – very difficult to use; 5 – very easy to use).
Currently we are finalizing the study with a total of 16 patients, and this one patient appeared to be representative for the general trends, which will be published later.

4 Conclusion

Through the user-involved design and validation of the WPD, we have shown that the WPD is feasible for clinical use in sub-acute stroke patients, as a support to maintain a correct and healthy sitting posture on the wheelchair, and that the use of the WPD reduces the number of times a specific representative patient had to be manually repositioned by a caregiver during a week by 50%. The device was rated as comfortable and easily usable by the caregiver while being rated by the patient as improving pain complaints.
With this preliminary result, the WPD provides an example that the Varstiff technology can be a very beneficial technology for improving supports and cushions in stroke care; because of its typical capacity to be shaped in a flexible state according to the needs of a specific user, and to become rigid once formed to a functional shape.

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