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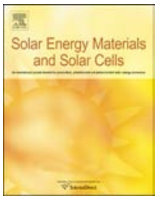

Thermo-mechanical characterisation of fluoropolymer films for concentrated solar thermal applications

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ABSTRACT

Renewable and clean energy sources are getting more important. Therefore, a resource-saving alternative to conventional solar concentrators has been designed. This pneumatic pre-stressed concentrator is completely made of polymer films. Due to its pre-stressed construction the mechanical properties of the transparent film have a high influence on the lifetime of the concentrator. The dimension stability of the film significantly affects the effectiveness of the systems due to the shift of the focus point of the reflected radiation after deformation. Therefore, special requirements concerning thermal and mechanical properties in the application relevant temperature range have to be fulfilled.

The aim of this work is to characterise fluoropolymer films as transparent layers in a pneumatic pre-stressed sun concentrator. Fluoropolymers have been chosen due to their excellent optical and mechanical properties and their extraordinary stability against ultraviolet radiation. A total of five different fluoropolymer films have been selected and their thermal, mechanical and thermo-mechanical properties at application relevant temperatures were characterised. Even though no material complies with the requirements, an ethylene-tetrafluorethylene-copolymer (ETFE) is suggested, with the recommendation to adapt and adjust the film thickness and the production process to influence the morphology and subsequently the thermo-mechanical behaviour of the material.

1. Introduction

The limited fossil resources, the growing demand for energy and the climate and environmental protection efforts significantly increase the importance of renewable and clean energy sources. One of these energy sources is the sun, which has enormous potential. To utilise this energy type, large-scale and cost-saving solar thermal power plants are used. A resource-saving alternative to conventional collectors are inflatable types which are already 'state of the art' and patent registered [1–9]. Several different approaches were made: e.g. Bertrand et al. used a circular polymer membrane as a reflective unit and a transparent membrane which were gas proof and were fixed in a frame. The subsequent inflation caused an almost parabolic bending of the reflective film and the incoming radiation was focused on a suitable medium. The transparent film exhibited less bending than the reflective film [4]. Clark et al. used a box-shaped apparatus which contained a number of inflatable tubular chambers connected to air pumps at one end [6]. The approach by Piotrowski included an inflatable cell supported in a frame. Each cell included two bladders – a transparent outer one for isolation and a blackened inner bladder which contained a suitable heat medium. Both bladders included at least one vent hole for medium flow [5]. Cummings applied a similar approach as Bertrand; one transparent and one reflective film were bonded and inflated to concentrate solar radiation. However, the embodiment was a nearly spherical collector which may be supported by a circumferential belt at the bonded line [9].

One selected approach of a pneumatic pre-stressed concentrator type is completely made of polymer films (Fig. 1) – the reduction of the material usage per m² by a factor of 10 compared to conventional parabolic mirror collectors with almost similar degree of efficiency. Regarding this, prototype experiments showed possible fluid temperatures up to 320 °C with a concentration index of around 50.

The concentrator consists of three different polymer films – an upper transparent, a middle reflective and a bottom robust film. The middle film separates the internal space into two gas proof chambers. The upper chamber exhibits higher pressure than the bottom chamber, which causes a bending of the middle reflective film. Thus the bended reflective film directs the incoming radiation to an absorber. Due to this pre-stressed construction, the pressures highly influence the location of the focus point and are therefore of importance regarding the effectiveness of the concentrator. For example, model calculations showed that a pressure deviation of p_1 of about 5% can

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cause a decrease of the degree of efficiency of more than 40%. Concerning this matter also the mechanical properties of the films influence not only the lifetime of the concentrator, but also the effectiveness. The reason for this is that a very high dimension stability is required due to a possible shift of the focus point of the reflected radiation after deformation.

Many different transparent materials have been tested for their utilisability for solar applications [10–12]. However, not all of them are suitable for use in a pre-stressed concentrator. For instance poly(methyl methacrylate) copolymer (PMMA) can be excluded because of a glass transition (75 °C) at application relevant temperatures which can cause a massive decrease in the effectiveness of the concentrator due to dimension deflection [12]. Moreover the low scratch resistance of PMMA and polycarbonate (PC) is the reason why those materials are not ideal for the application in a polymer concentrator [13,14]. Scratches on the surface or abrasion can cause light scattering and this results in a decrease of the effectiveness as the incoming radiation should be mainly directional. The most promising material class are the fluoropolymers, on the one hand, because they exhibit excellent optical properties with low refracting indices of about 1.35–1.4 and on the other hand because of their high resistance against weathering [15–19]. Therefore, in a previous study fluoropolymer films have been pre-selected for investigation of their mechanical qualification as transparent film in a pneumatic pre-stressed sun concentrator. As stated before the mechanical performance for the whole application relevant temperature range (−10 °C to 100 °C) is of enormous significance and this involves also a first screening of the crack behaviour which strongly influences the lifetime of the concentrator. Limits for mechanical parameters were defined by a modelling process – yield stress value and a maximum force value (for notched samples) of at least 1.6 N/mm are required. For a better comparison the film thicknesses of the materials were eliminated, which means that the limits are only related to the film width and not on the film thickness. Moreover the detection of transition temperatures is essential in order to eliminate the risk of choosing a material which exhibits a transition temperature in the range of the application relevant temperature of the sun concentrator due to a possible dimension deflection.

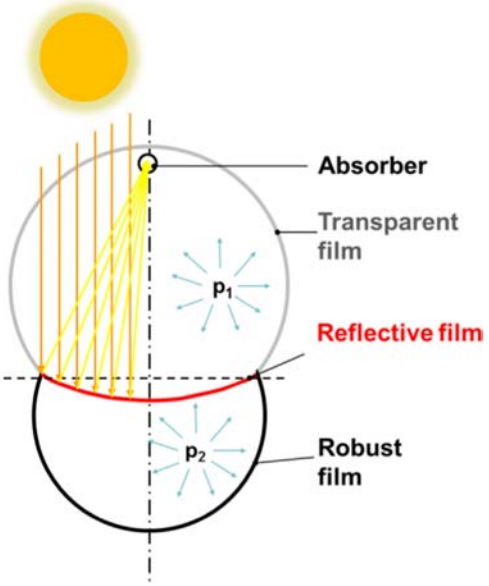


Fig. 1. Schematic build-up and operation method (vertical cut through the collector).

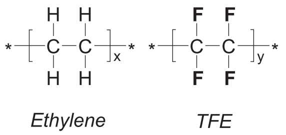
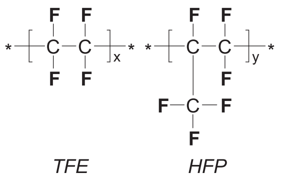
The main objective was to analyse pre-selected fluoropolymers to ensure they fulfil the above mentioned requirements at application relevant temperatures (−10 °C to 100 °C) by thermal, mechanical and thermo-mechanical test setups [20,21].

2. Experimental

2.1. Materials

A total of five transparent fluoropolymer films were characterised: three different ethylene-tetrafluorethylene-copolymers (ETFE), one tetrafluoroethylene-hexafluoropropylene-copolymer (FEP) and one tetrafluoroethylene-hexafluoropropylene-vinylidenefluoride-terpolymer (THV) (Table 1). In order to achieve the addressed objectives the thermal, mechanical and thermo-mechanical properties were characterised by differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA) and tensile testing.

Table 1
Pre-selected polymer films.

Material		Thickness	Structure
ETFE 1 ETFE 2 ETFE 3	Ethylene-tetrafluorethylene (TFE)-copolymers	230 μm 150 μm 100 μm	
FEP	Tetrafluoroethylene (TFE)-hexafluoropropylene (HFP)-copolymer	200 μm	
THV	Tetrafluoroethylene (TFE)- hexafluoropropylene (HFP)-vinylidenefluoride (VDF)-terpolymer	200 μm