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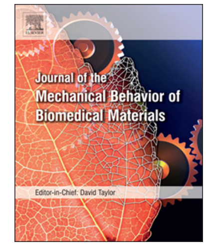

Research paper

Performance enhancement of epoxy based sandwich composites using multiwalled carbon nanotubes for the application of sockets in trans-femoral amputees

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ABSTRACT

A socket plays a vital role in giving the comfort to the amputees. However, the accumulation of heat inside the socket and its weight led to increase their metabolic cost. Hence, an attempt was made to increase the performance of the epoxy based sandwich composites to be used for the socket by reinforcing multiwalled carbon nanotubes (MWCNT), which was varied from 0.1 to 0.5 wt%. It was homogeneously dispersed in epoxy to obtain the desired properties, where the enhancement of thermal conductivity, compressive strength and modulus of epoxy was observed to be 76.7%, 62.6% and 20.2%, respectively at 0.3 wt% of MWCNT concentration beyond which the mechanical properties were found to be decreased. Hence, the epoxy, E-glass plain fabric, 2–10 layers of stockinet and 0.3 wt% of MWCNT were used to prepare the sandwich composites. The flexural strength and thermal conductivity of 0.3 wt% of MWCNT reinforced sandwich composites were found to be improved by $11.38 \pm 1.5\%$ and $29.8 \pm 1.3\%$ for the 4–10 layers and up to 10 layers of stockinet, respectively compared to unreinforced sandwich composites, which helped to reduce the weight of the socket and decrease the heat accumulation inside the socket. Thus, it is suggested to be explored for the application of socket in trans-femoral amputees to increase their comfort level by decreasing the metabolic cost.

1. Introduction

The leg amputation in the active person is the most uncomfortable surgery in a patient's life. The locomotive disability in India contributed to 27.9% of 2.13% of the total disabled population in 2001 and 20.3% of 2.21% of total disability in 2011, as per the census India (Census India, 2001). The national limb loss information center, USA reported that one out of every 200 people in U.S. has had an amputation. It was also reported that nearly 1.7 million people in USA has been living with limb loss (NLLIC Staff, 2008). Out of the total amputation, upper extremity amputee (UEA) and lower

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extremity amputee (LEA) constituted 13% and 87%, respectively. Among the LEA, the below knee amputee (BKA) and above knee amputee (AKA) constituted 62% and 38%, respectively.

The trans-femoral prosthetic device consists of a socket, knee joint, pylon and foot. The bottom of the trans-femoral socket was connected with the prosthetic knee joint along with the pylon and sach foot for achieving the flexion–extension of the amputed leg. The socket has direct contact with the residual stump, which also helps to have a qualitative improvement on the performance of the prosthetic devices. The usage of available prosthesis was limited due to the tissue ulcerations, where an amputee was forced to depend on the crutches and wheel chairs (Hynd et al., 2000). Lacroix and Patino (2011) reported that the soft tissues transferred the load during gait after the fixation of prosthesis, which created blisters in the stump. Portnoy et al. (2007) described that the transfer of load via soft tissues in the stump led to the formation of callosities and abrasions, which increased the metabolic cost of an amputee. An increase of moisture and temperature inside the socket created skin maceration causing the bacterial invasion. Pain created by pulling the liner and the wrinkling in the liner and socks during the function of the knee were also the influencing factors for the ineffective function of the socket (Cochrane et al., 2001). Currently, the existing socket system acted as a physical barrier by limiting the rate of heat transfer. The accumulation of heat inside the socket led to raise the temperature of residual stump and it was found that the temperature raise of 1 °C led to increase the metabolic cost of an amputee by 10%. Some other factors which determine the performance of the socket are personality factors, general physical factors and social and economic factors (Arthur et al., 2001). Though all the factors cannot be taken care by the research community, the material related issues such as thermal conductivity, specific heat, weight, friction at the skin–socket interface and the pressure developed can be modified in order to increase the comfort level or reduce the metabolic cost of an amputee.

The socket made of thermoplastics or thermoset plastics acts as a link between the amputee's residual limb and the prosthesis. In case of thermoset plastics, the polyester, epoxy, and polyurethane have been used. Thermoplastics such as polyethylene terephthalate (PET), polymethyl methacrylate (PMMA), poly propylene (PP) and Derlin $(CH_2O)_n$ were used for the fabrication of sockets. Current et al. (1999) prepared the socket from the epoxy, acrylic and polyester based composites. The reinforcement materials used in their study were stockinet fabric, E-glass, aramid, nylon and carbon fiber. Among all resins tested in their study, the epoxy resin was preferred because of its low cost combined with good mechanical properties and availability.

The required properties of the polymer can be achieved using the reinforcement of nanoparticles. Among all the fillers, multiwalled carbon nanotubes (MWCNT) were paid a lot of attention because of their attractive mechanical and electrical properties (Gojny et al., 2005; Maleh et al., 2013, 2014). Gojny and Schulte (2004) reported that the functionalization of MWCNT increased the interfacial interaction between the polymer and MWCNT. Park et al. (2008) investigated the influence of different solvents such as 2-propanal, ethanol, acetone and water for the homogeneous dispersion of MWCNT with epoxy resin using electrical resistivity technique, where the acetone was found to be a suitable solvent for the same. Arun et al. (2013) used three different methods for drying the acetone such as (1) magnetic stirring at 55 °C, (2) hot air oven drying at 55 °C, and (3) vacuum drying at room temperature for the dispersion of MWCNT in epoxy. It was observed that the mechanical properties of the composites prepared by vacuum processing method were found to be superior compared to other processing techniques. It was noticed that the optimized concentration of reinforcement used for improving the characteristics of epoxy based sandwich composites was not reported. Hence, an attempt has been made to optimize the MWCNT concentration and fabricate the MWCNT reinforced sandwich composites in order to improve the thermal and mechanical properties of the socket material for the possible reduction of the metabolic cost of an amputee.

2. Materials and methods

2.1. Materials

The MWCNT was purchased from M/s Shenzhen Nanotech Port Co., Ltd., China. The specifications of as received MWCNT are as follows: outer diameter 10–20 nm, length 5–15 μm, purity-97 wt-%, ash content <3 wt%, density 2.16 g/cc, specific surface area> 250 m^2/g. Epoxy resin and hardener having the density of 2.25 and 0.94 g/ml, respectively were purchased from M/s Endolite, India, Inc., where the stockinet and E-glass woven fabric were also purchased.

2.2. Preparation of chemically treated MWCNT

The MWCNT was chemically treated in order to have the strong bonding with epoxy as well as to remove the substrate impurities. The MWCNT was heated with nitric acid and sulfuric acid mixture having the volume ratio of 1:3 at 140 °C in an oil bath with continuous stirring for 30 min, as suggested by Wang et al. (2002). Then, the MWCNT was washed with deionized water till the supernatant showed a pH value of around 7. The same was dried in a hot air oven at 100 °C to remove the moisture content and then ground to get the fine powder of MWCNT. It was noted from the Fourier transform infrared spectroscopy (FTIR) studies that the acid treated MWCNT has different functional groups on its surface. The peaks identified at 1376, 1577, 1695, and 3353 cm^{-1} were attributed to the presence of C–O, C=C, C=O and O–H bonds, respectively in the chemically treated MWCNT.

2.3. Preparation of composites

The resin and hardener having the weight ratio of 1:0.4 were hand-mixed using a stirrer rod for 15 min. and the mixture was poured into the die having the dimension of 50 mm length and 8 mm diameter. The mold was then allowed to cure at 26±2 °C for 3 h, and the pure epoxy specimen was obtained. The composites samples having 0.1, 0.2, 0.3, 0.4 and