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DESIGN OPTIMIZATION FOR CRUTCHES PADS FOR THE DISABLED TO PREVENT THE SLIPPAGE ON ALTERED FLOORS

Ibrahim A. M. M.[1], Helal M.[2,3]

[1]Production Engineering and Mechanical Design Department, Faculty of Engineering, Minia University, Egypt.
[2]Department of Mechanical Engineering, Faculty of Engineering, Taif University, KSA.
[3]Production and Mechanical Design Dept., Faculty of Engineering, Mansoura University, Mansoura, Egypt.

ABSTRACT

The design of the “Crutch” is very important to avoid slipping during walking for the disabled on different floors. It is known that the uses of crutches are limited to specific floors. The recent research aims to redesign and optimize the pads for these crutches to extend their uses on different floors. Fabricating small grooves and surface modification in specific patterns are suggested approaches to increase the friction and the adherence properties between the crutch’s pads and the different types of floors. Furthermore, metallic elements could be used side by side with the grooved rubbers. The frictional behavior of different pads with different designs has been simulated to observe the sticking mechanism of these pads. Moreover, the optimal design has been obtained. In conclusion, the recent research suggests a new design for the crutch pads to offer a safer walking practice for those people who use the walking aid equipment.

KEYWORDS

Crutches, Disabled, Friction, Slippage preventing, Optimization.

INTRODUCTION

It is well known the importance of the aiding equipment for disabled. These devices facilitate the daily life of the disabled and it helps in the integration of the disabled in the surrounding society. The efficiency and safety considerations of these devices are taking the majority of the attention. One of the most common helping devices is the walking “Crutches”[1-3]. The design of the crutches is very essential to prevent slippage over different types of floors. Many attempts have been done to reach the optimum design of these pads [4]. Pads are mainly made of rubber and some groove patterns could exist at the lower surface of these pads. The main function of the grooves is governing the walking, carrying the loads, and prevent slippage during walking.

Allan and Scott [5], showed that when the confounding effects of surface asperities are removed, subjects are able to accurately assess the friction of smooth surfaces by stroking the finger over the test surface. The subjects can accurately scale relative differences in the friction of macroscopically smooth, flat surfaces, by modulating the tangential force applied to the finger while keeping the normal force relatively constant.
Thys et al. [6], measured the energy consumed and the mechanical work performed during swing-through crutch gait in order to assess if the greater energy expenditure is accompanied by an equivalent increase of the work done to move the body. They showed that depending upon the speed, the energy expenditure is 2-3 times higher in swing-through gait than in normal walking. On the other hand, the mechanical work increases only 1.3-1.5 times. Olle [7] found that static skin friction is lower than dynamic friction and that increased velocity increases the coefficient of friction, but increasing load reduces it. Two regression models were developed. Regression coefficients are presented for surface topography variables as well as skin condition and contamination, velocity surface pressure, and discomfort. Two new surface topography representations explain the generation of friction forces. The uppermost 5% of the volume of texture peaks provided significant information for the transfer of friction forces. Adriana [8], measured kinetic variables such as ground reaction force, rate of force rise, and impulse and spatiotemporal variables such as stride length, stride time, and percentage of stride spent instance. The use of spring-loaded crutches altered the mechanics of crutch gait in ways that are likely to reduce overuse injury in crutch users. The rate of ground reaction force rise and impulse of the ground reaction force (both P<001) were reduced by 33% and 13% to 26%, respectively. On the other hand, David et al. [9] quantified the effects on the slip resistance of the application of marking paint on several common walking surfaces. Results indicated that even in the absence of any additional surface roughening additives (e.g., sand, rubber grit, or glass beads), the application of purpose-designed marking paint to walking surfaces such as those found in most commercial outdoor areas.

Christopher et al. [10] aimed to assess the viability of using slip risk (as quantified during human subject walking trials) to create a reference standard against which tribometer readings could be compared. They revealed that only two of the nine tribometers tested (Tortus II and Mark III) met our compliance criteria by both correctly ranking all six conditions and differentiating between surfaces of differing degrees of slipperiness. Yoshikazu et al.[11] proposed a standing style transfer system ABLE that helps users with disabled lower limbs to enjoy mobility without special infrastructure. ABLE comprises a pair of telescopic crutches, a pair of mobile platforms, and a powered lower extremity orthosis. They proposed the telescopic Lofstrand crutch as a substitute for the telescopic shoulder crutch. The merit of the telescopic Lofstrand crutch is its lightweight because it has no motor.

Daniel et al. [12] illustrated the dynamic effects of using a kinetic shape as a crutch tip on a swing through crutch walking (non-weight bearing). They showed that introducing a KCT to crutch walking can alter step length and swing time asymmetries during overground walking. Participants walking with a forward forcing KCT experienced a reduction in the horizontal ground reaction forces of up to 74% compared to walking on standard rubber crutch tips. The backward forcing KCT reduced the heel strike peak forces by as much as

27%. These findings show that crutch walking dynamics can be customized and optimized to yield a specific crutch walking behavior tailored to various user needs or walking environments. Fatemeh et al. [13], focused on the difference between the Kinetic Crutch Tip (KCT) and a Standard Rubber Tip. Moreover, the effect of KCT stiffness on the crutch gait cycle and the reaction forces were investigated. They indicated that an increase in maximum backward angle for Kinetic Crutch Tips. This increase in the rotation angle shows an improvement in the forward motion of the crutch Alex et al. [14], investigated how crutch tip designs affect the user's gait. Five Kinetic Crutch Tips (KCT), each with different durometers (i.e., stiffnesses) along with one carbon fiber reinforced nylon 3D printed KCT and one Standard Rubber Tip were tested. It was found that the KCT had a larger transitional angle than the Standard Rubber Tip. This increases the assistive forward forces of the crutch due to the surface kinetic shape of KCTs; however, the total angle of different crutch tips remains the same when used by the subjects.

The main aim of the recent research is to improve the load capacity and the frictional properties of these pads towards appropriate and safe use over a wide range of floors through finding the optimum arrangement and pattern of the grooves.

THE PROPOSED DESIGNS OF THE PADS

There are 4 proposed designs and the walking operation will be simulated by ANSYS finite element package. The results of the proposed designs will be compared with the old design. The old design and the proposed designs are shown in Fig.1.

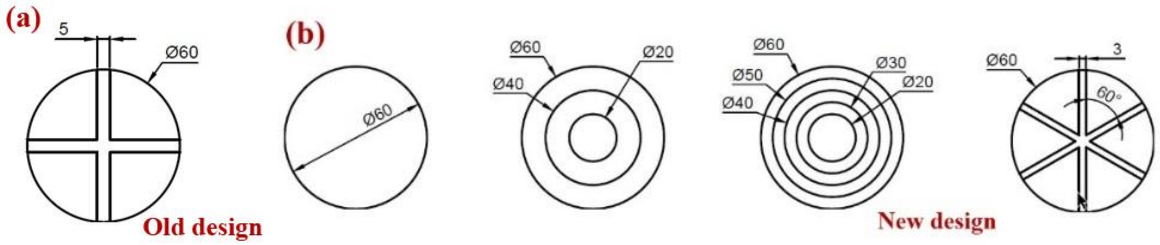

Fig. 1 Old (a) versus new designs (b) [all dimensions in mm].

The model assumptions are that the "Crutch" can carry one-third of the total weight of the person (on average 80 Kg), The pads are made of natural rubber with a density of 9×10^{-3} Kg/mm^3, while the modulus of elasticity is 1.5 MPa. Furthermore, Poisson's ratio is considered as 0.3. The mesh of the model is shown in Fig. 2.

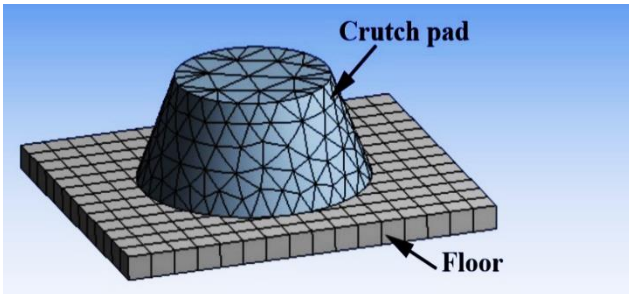

Fig. 2 The mesh of the pad-floor system model.

THE SIMULATED RESULTS

Figure 3 shows the directional deformation of crutches pads under the applied pressure, while the body is starting to move. Therefore, the friction is considered static friction. It is clear that the new design of the pad which contains one 5 mm groove recorded the maximum deformation in X-direction. Moreover, the design which contains two grooves with 3 mm grooves recorded the second-largest deformation in X-direction. Meanwhile, the old design recorded the third lowest value of the deformation in the same direction. While the pads without any grooves recorded the minimum value of deformation. Figure 4 shows the directional deformation in Y-direction for the five designs. The same trends could be notices as the deformation in Y-direction. The maximum deformation is recorded by the design which contains one 5 mm groove. While the old design recorded the third minimum value. The worst behavior is recorded by pads without any groove.

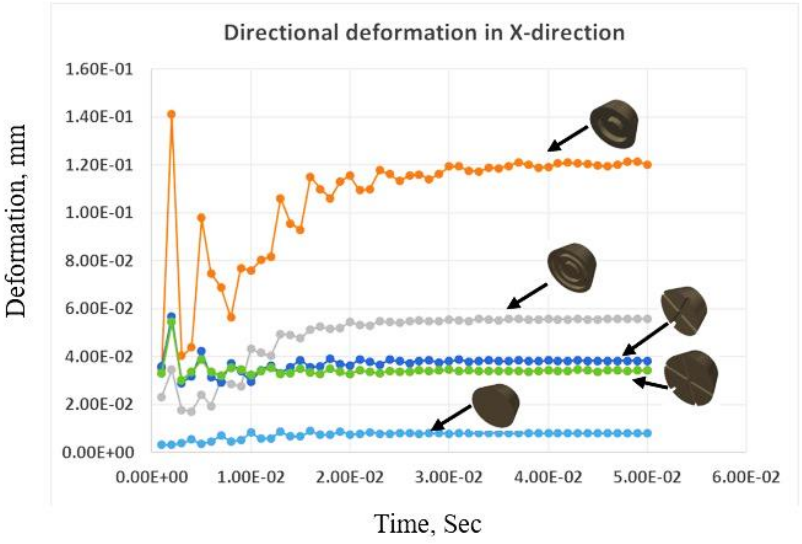

Fig. 3 Directional deformation in X-direction.

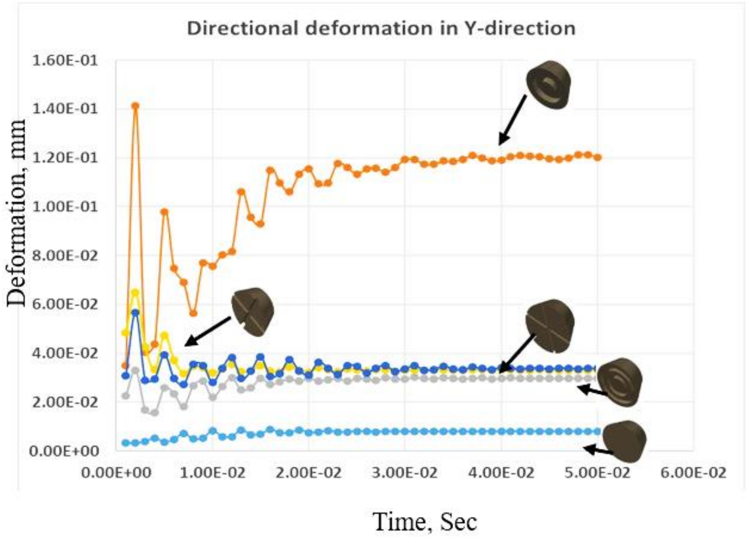

Fig. 4 Directional deformation in Y-direction

As shown in Fig. 5, it is observed that the resultant deformation could be obtained with pads with one 5 mm groove (see Fig. 5 (b)). While the minimum value is recorded by pads without any groove. The old design recorded the third minimum value of resultant deformation. By means, the maximum contact area can be reached using pads with one 5 mm groove. Moreover, the pads without any groove recorded the minimum contact area.

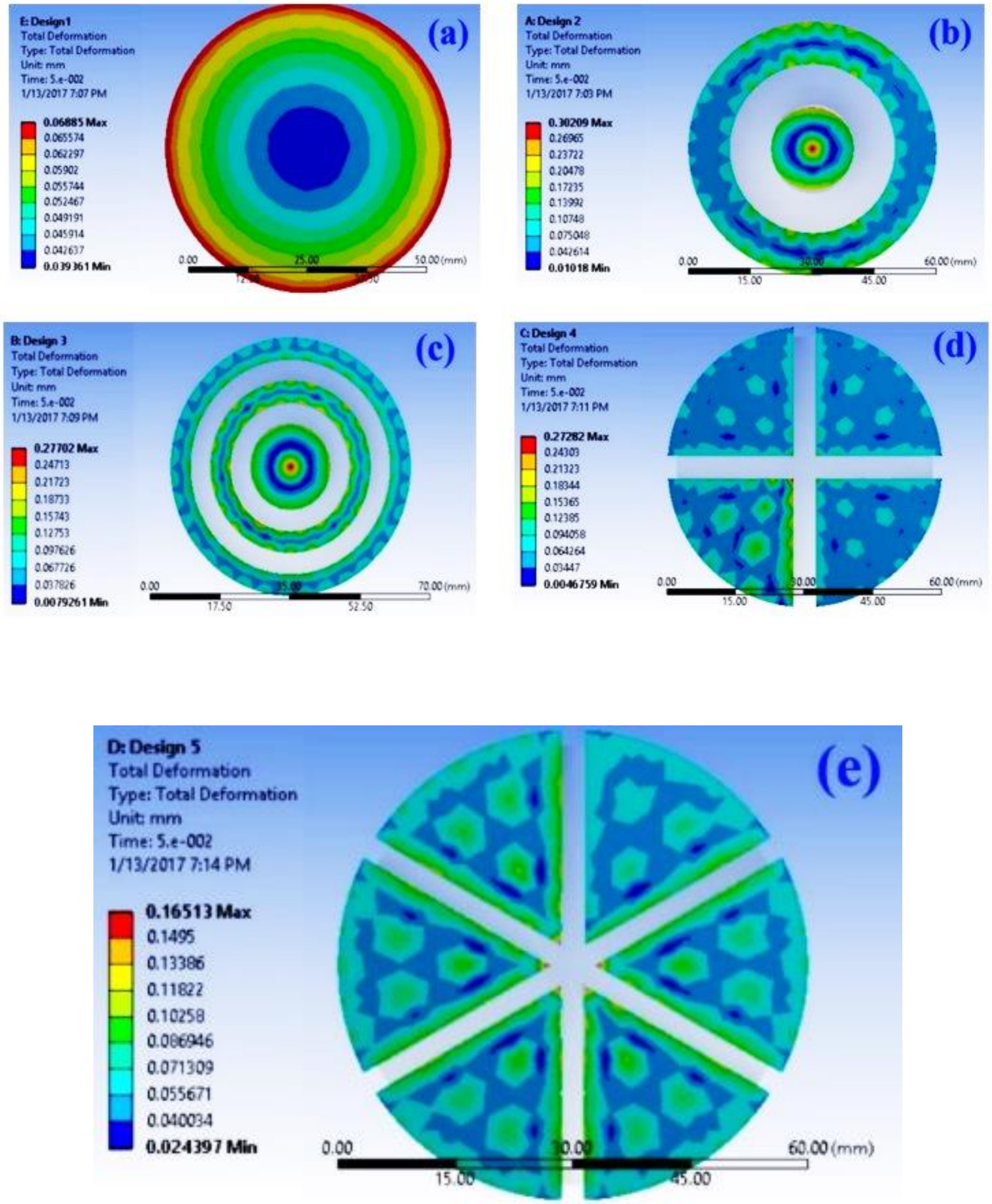

Fig. 5 Resultant deformation distribution of different patterns of the pads.

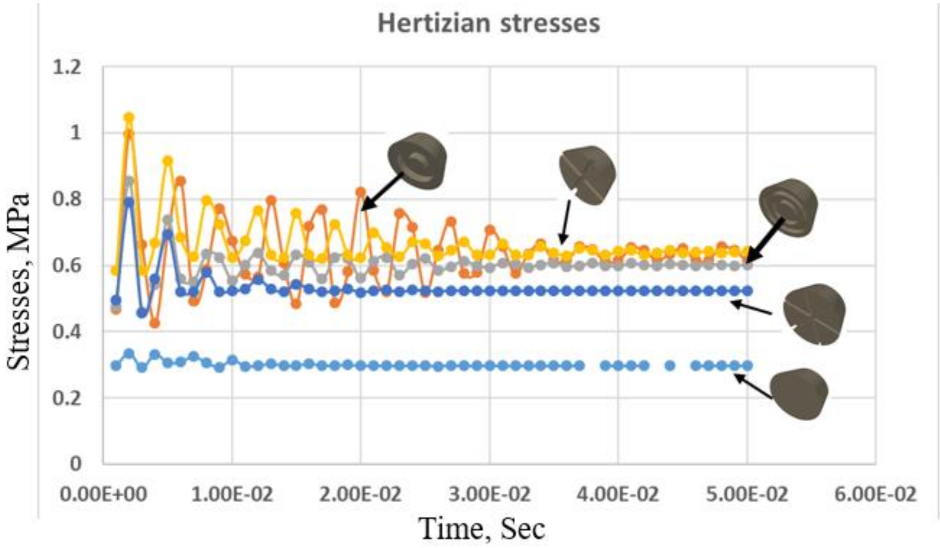

Fig. 6 Hertzian stresses acting on the pads.

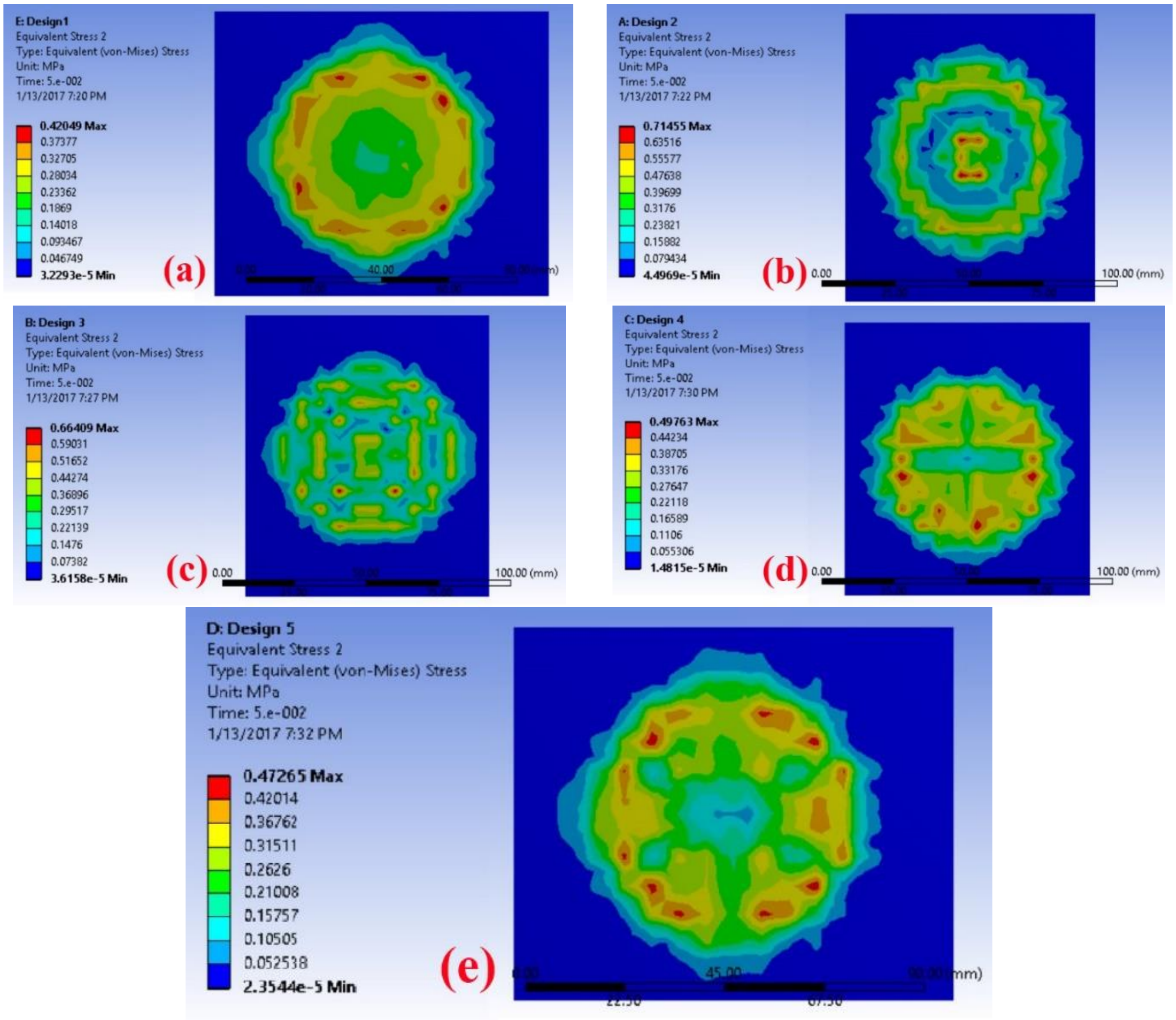

Fig. 7 Hertzian stresses acting on the floors under the sliding and pressure.

Figure 6 shows the Hertzian stresses acting on the old and new designs of the pads. It is estimated that the Hertzian stresses are directly related to the contact areas. The maximum stresses are recorded with one 5 mm pad design. While the minimum values of Hertzian stresses are recorded with no groove pads. The same behaviors are noticed for the Hertzian stresses acting on the floors under the sliding and pressure. It is shown that the Hertzian stresses increase as the contact areas increase as shown in Fig. 7. Furthermore, the Hertzian stresses are concentrated in the center of the crutch pad. Nevertheless, the Hertzian stresses are concentrated on the edges of the pads for the other designs.

DISCUSSIONS

As shown in the previous figures, the largest contact areas could be reached when using a pad one 5 mm groove. Furthermore, the Hertzian stresses are the maximum for the same pad design. The stress concentration zone has been estimated in the center of the contact for the same pad design. The old design recorded the third lowest contact area and Hertzian stresses. The zones of stress concentrations tend to be at the outer edges of the pads away from its center.

The worst behavior was recorded for the pads without grooves. This behavior could be interpreted in the bases that for the one 5mm groove pads, while the pressure is applied on the pad, the inner and outer rubber rings begin to expand and deform in radial directions outward the outer diameter, which leads to a dramatic increase in the contact area. This increment of the contact area ensures good and sufficient stability during the walking over different types of floors. Moreover, the concentrated Hertzian stresses zone exists at the center of the pad, which ensures that the expansion of the pad during the contact is directed outward instead of inward direction without restriction. This behavior makes this design as a self-adapted design according to the acting pressures and floor types.

For the old design, the direction of the grooves restricts the expansion of the pads during loading, which leads to a restricted increase in the contact area. Another reason may explain this restriction of the contact area. This reason is the existence of the high-stress concentration zones at the outer side of the pads away from the centers, which forces the expansion in the inward direction instead of the outward direction.

CONCLUSIONS

1. **The directions of the grooves affect the contact areas of the crutch's pads.**
2. **The circular grooves perform better than the straight grooves.**
3. **The existence of the high-stress zones near the center of the pads helps in ensuring the stability of the pads during contact.**
4. **The large increase in the contact area during the loading ensures more stability for the crutches.**

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