EXPERIMENTAL AND THEORETICAL INVESTIGATIONS OF DORSIFLEXION ANGLE AND LIFE OF AN ANKLE – FOOT – ORTHOSIS MADE FROM (PERLON – CARBON FIBRE – ACRYLIC) AND POLYPROPYLENE MATERIALS

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Abstract

Experimental investigations in present paper were divided into: dorsiflexion and fatigue tests. Dorsiflexion test was done for (perlon-carbon fibre-acrylic) materials and ordinary solid designs of orthoses are 8.2° and 7.7° respectively using "Dartfish program". The fatigue test was achieved on prosthetic foot worn sole and measured life of sole found to be 2.137 x 106 cycles. The theoretical AFO lives were equal to 1.0 x 107 and 2.3 x 106 cycles for calf and sole parts respectively; while theoretical dorsiflexion angle of sole is equal to 8.266°.

Key words

AFO, Fatigue analysis, Perlon-Carbon fiber-Acrylic materials, Dartfish program, Sole life.

1. Introduction

Dartfish is the world's leading video analysis software for all sports, biomechanical and in broadcast applications, this technique moved it's focus to coaching applications. From skill analysis and game film breakdown to video casting. Dartfish helps coaches to teach more effectively, and athletes improve faster. Dartfish currently has over 100,000 clients, including Olympic federations, professional sports teams, academies, universities and clubs all over the world [1].

Researcher and instructors can use Dartfish to view and analyze video clips, capture skills and compare content. Dartfish allows to run comparisons, analyze movements and trajectories, calculate speeds and demonstrate key technique and position. Dartfish program was used to get the angular assessments from stick figures representations of the human leg, then the Spatial - temporal variables (angle, time, and distance) are measured during mid-stance (foot flat) and toe-off phases of gait cycle [2]. In free speed walking, human gait is a quasi-periodic activity with the left and right limbs out of phase. Control of the whole body, and specifically the lower limbs, is often described in terms of the magnitude of parameters at key events and during key phases that occur during the gait cycle [3].

The stresses measured in solid AFO were either tensile or compression stresses due to bending during motions. The maximum tensile stresses of the various and standard AFO were 0.35 MPa and 0.84 MPa respectively, while maximum compressive stresses 0.5 MPa and 0.6 MPa were located at the lower neck [4]. The strain gauge was bounded to the surface of the solid AFO, the strain information obtained in the solid polypropylene AFO during gait activities are the principal strain and allow determination of the maximum stress which maximum at middle – lower lateral neck [5]. Three orthoses were constructed with different curvatures cut out of the malleolar regions, these orthoses were then tested in failure for 500,000 cycles at 5 Hz in displacement control with initial displacements were set to provide maximum loads of 45 Ibs [6]. High stress concentration in the neck region is consistent with the common clinical observation that AFO's break down in the neck region [7]. In present paper, experimental and theoretical investigations were done on new AFO made from two parts calf (made from PCA materials) and sole (made from PP material) connected together by rigid neck joint. Two more important items were measured and estimated here, dorsiflexion angle and life with comparison were made between experimental and theoretical results and between PCA calf and PP calf of AFO under fatigue loading.

2. Experimental results

2.1 Fixed plate test

The ground reaction force (GRF) was developed under sole, due to biomechanical effects on leg during gait and stance cases, can be tested for patient has drop foot in its left leg using fixed plate device or as called "ZEBRIS" connecting directly to computer by UBS cables as shown in Fig.1 . The GRF was determined in this test by let patient, 72 kgm weight has drop foot in left foot only, walking over fixed plate. The average temporal ground reaction force over gait cycle for left foot, drop foot worn AFO, can be shown in Fig. 2 which necessary to determine to applied next as input data in dynamic theoretical solution for sole.

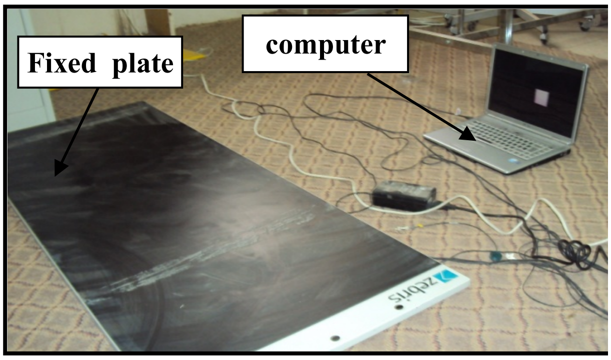


Fig. 1: Fixed plate device

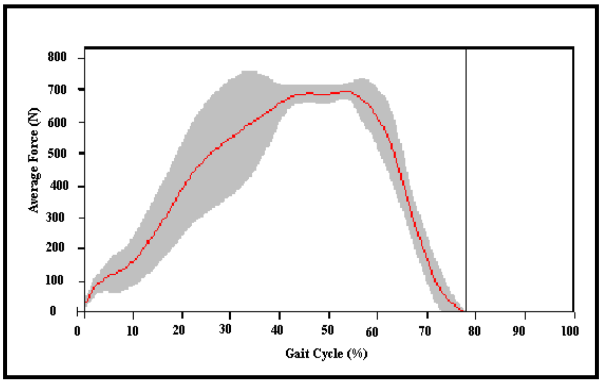


Fig. 2: Average force versus gait cycle for left foot

2.2 Fatigue test

In current test, examination of a fatigue life of AFO experimentally was carried on by applying reciprocating and sequence of a forces on heel and toe – off regions of a standard prosthetic limb wear a sole using pneumatic fatigue device for prosthetic limbs tests. The magnitude of reciprocating force has been taken in our test is equal to ***1.3*** of patient weight (72 kgm) by suitable adjusting of frequency timer and setting compressor valve at ***2.5*** bar.

To avoid clearance between sole and prosthetic foot during operation, two ***3 mm*** diameters screws were used, one of them at heel and second near toe – off zones. After test would been done, the sole failure has been detected as shown in Fig.3 due to introduce crack at the bottom surface of sole after (***2137233***) cycles.

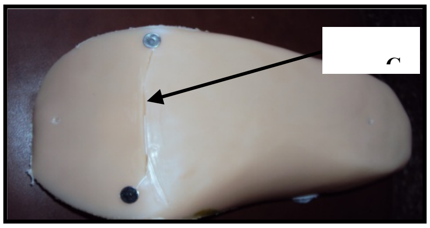


Fig. 3: Sole fatigue failure after test

2.3 Material tensile and fatigue tests:

The fatigue solution for calf and sole parts of AFO orthosis are required stress – life curve which can be investigated using fatigue test device. To determine required parameters in calculations of amplitude stresses of PCA materials under cyclic reversed fatigue loading, by using monogram can be done by taking materials mechanical properties, Table 1, which investigated in current work by using tensile test.

Table 1: Mechanical properties for PCA and PP materials

Material	Young's modulus E (GN/m2)	Yield stress σy (MN/m2)	Ultimate stress σu (MN/m2)	Possions ratio
PCA	1.634	32	33.75	0.35
PP	0.812	21	28.75	0.42

The suitable range of deformation in bending test specimens which clearly determined from monogram are:

$$\delta = 1.5 \text{ to } 4.75 \text{ mm.}$$

Fig.4 shows the investigated stress – life diagram for PCA materials when the bending deformation varies from 1.1 to 5.25 mm against number of cycles for which the specimen bricking down. The stress – life curve for PP material was already available in references as shown in Fig.5. The best fit equations for two diagrams, Figs.4 and 5, under study can be investigated respectively as follows:

$$\sigma = 0.921\,(LOGN)^2 - 13.02\ (LOGN) + 56.06 \qquad (1)$$

$$\sigma = -0.098\,(LOGN)^3 + 1.824\,(LOGN)^2 - 11.67\,(LOGN) + 30.92 \qquad (2)$$

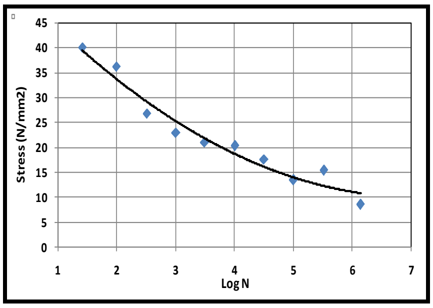


Fig. 4: Investigated S – N curve for PCA materials.

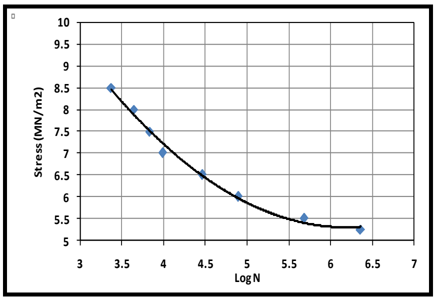


Fig. 5: S – N curve for PP material [8].

2.4 Dorsiflexion test:

The temporal angle variation of dorsiflexion angle at beginning and end of gait for drop foot patient was being worn new and ordinary AFO using dartfish program can be shown in Figs.6 and 7 respectively, while temporal angle for health man worn new AFO were clearly illustrated in Fig.8.

a) b)

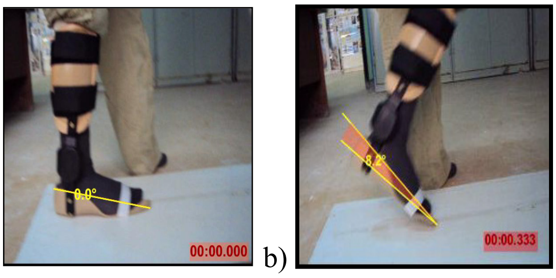


Fig. 6: Temporal dorsiflexion angle for patient wear present AFO, (a): t = 0, (b): t = 333 msec.

a) b)

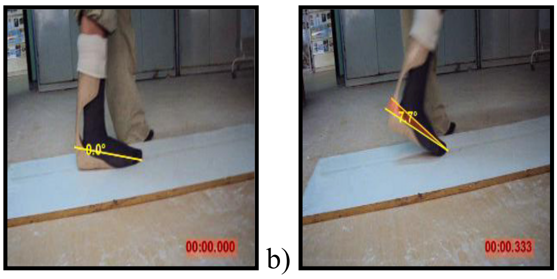


Fig.7: Temporal dorsiflexion angle for patient wear ordinary solid AFO, (a): t = 0, (b): t = 333 msec.

a) b)

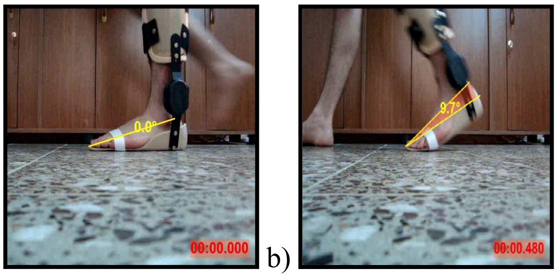


Fig. 8: Temporal dorsiflexion angle for health man wear new AFO, a): t = 0, b): t = 480 msec.

From previous images, the maximum dorsiflexion angles at toe – off phase are 8.2, 7.7, and 9.7 degrees for patient worn new design of AFO, patient himself worn ordinary solid AFO, and health man worn new orthoses respectively. The dorsiflexion angle variation with walking time steps are shown in Fig.9 for three cases under study.

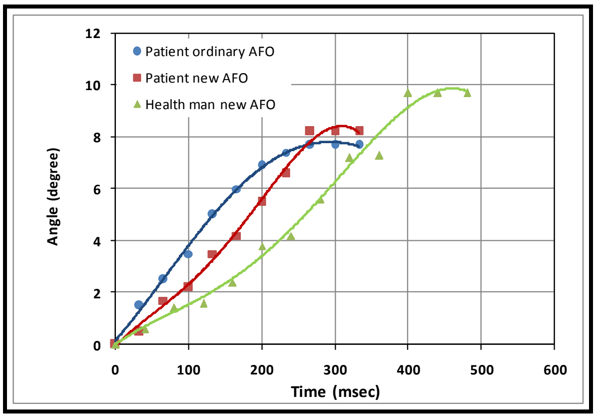


Fig. 9: Dorsiflexion angle verses walking time.

3. Theoretical results:

3.1 Dorsiflexion angle:

The theoretical vertical deflection of sole under static loading at toe – off region for patient has 72 kgm weight was 5.812 mm as shown in Fig.10 while horizontal contact length between sole and ground during toe – off stance is 4 cm; therefore theoretical dorsiflexion angle equal to 8.266o.

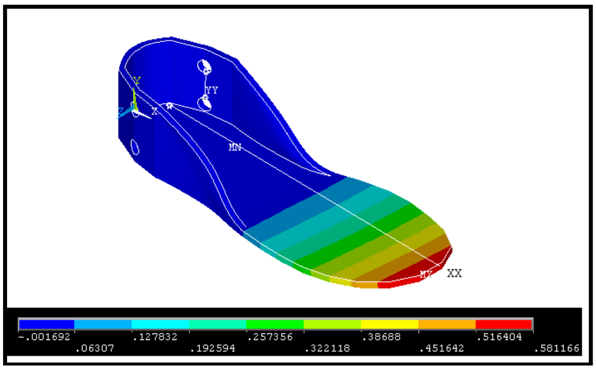


Fig. 10: Vertical deformation in (cm) for sole under toe – off loading.

3.2 Fatigue results:

The fatigue solution for PCA and PP calves has cut – out angle 25o under inner step-pressure loading over gait cycle shown in Fig.11 and by using investigated stress – life curves, Figs.4 and 5, can be done by ANSYS – WORKPENCH PROGRAM were illustrated its results in Figs.12, 13, 14, and 15 for total deformations, von – misses stresses, factor of safeties, and lives respectively.

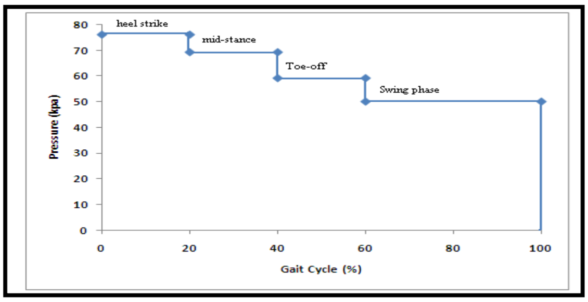


Fig. 11: Pressure-gait cycle loading for fatigue analysis.

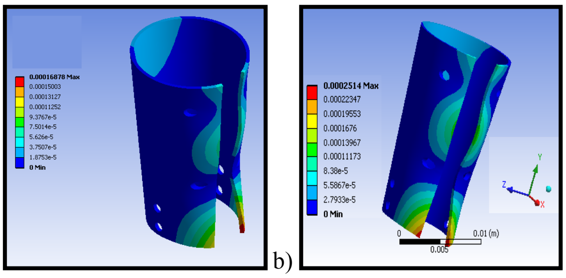


Fig. 12: Total deformation in (m) for 25o cut-out angle, a) PCA materials, b) PP material.

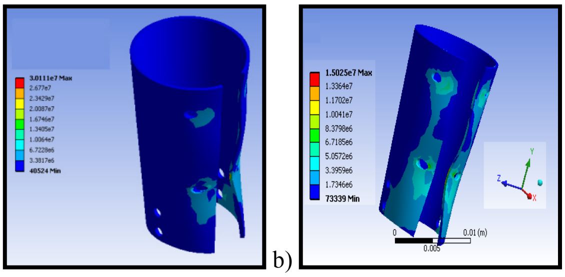
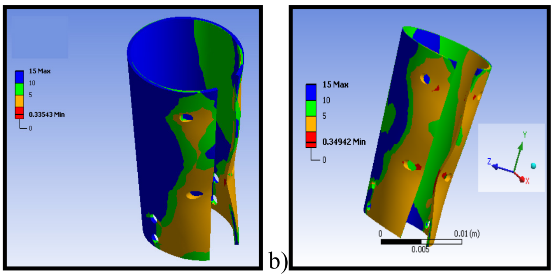


Fig. 13: Von – Misses stress in (N/m2) for 25o cut-out angle, a) PCA materials, b) PP material.



a) b)

Fig. 14: Safety factor for 25° cut-out angle, a) PCA materials, b) PP material.

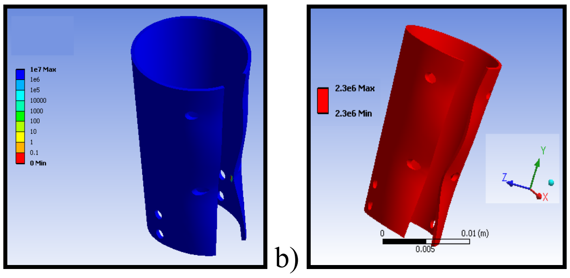


Fig. 15: Life in (cycles) for 25° cut-out angle, a) PCA materials, b) PP material.

The maximum deformations, Von – Misses stresses, and lives with minimum factors of safety induced in PCA and PP calves have cut – out angles 30° and 35° under fatigue loading can be determined and then collected with later results in Table 2.

Table 2: Fatigue results for calf has different cut – out angles

Fatigue item		Cut – out angle (degree)		
		25	30	35
Maximum deformation (mm)	PP	0.2514	—	—
	PCA	0.16878	0.06752	0.12922
Maximum Von-Misses stress (N/mm2)	PP	15.03	—	—
	PCA	30.11	13.97	12.55
Minimum factor of safety	PP	5	—	—
	PCA	5	5	5
Life (cycle)	PP	2.3 x 106	—	—
	PCA	1.0 x 107	1.0 x 107	1.0 x 107

The vertical deformation, Von – misses stress, factor of safety, and life induced due to fatigue loading on sole part can be shown in Fig.16. Table 3 was listed the experimental and theoretical investigation results in current paper for dorsiflexion angle and life of sole.

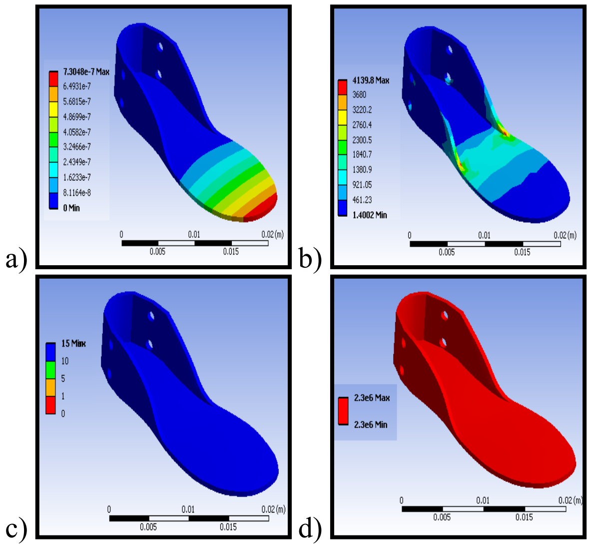


Fig.16 : Fatigue results of PP sole, a) deformation (m), b) Von-Misses stress (N/m2), c) Factor of safety, d) life (cycles).

Table 3: Theoretical and experimental comparison for dorsiflexion angle and life

Item	Dorsiflexion angle (degree)	Sole Life (cycle)
Theoretical	8.266	2.30 x 106
Experimental	8.20	2.137 x 106

4. Discussion

The new design gave higher dorsiflexion angle, 8.2°, than ordinary one, 7.7°, by increasing in percentage amount of 6.1 %. The new design of AFO reduced the dorsiflexion angle from actual dorsiflexion of health man foot of a 10o to 9.7o, that's means percentage reduction of 3 % because the PP sole work to prevent normally bending of foot to some less amount only. The theoretical dorsiflexion angle could be obtained only by tangent inverse of determined vertical deflection at sole tip divided by horizontal contact between foot (worn sole) to ground, which equal to 8.266°.

The maximum deformations were 0.16878 and 0.2514 mm for PCA and PP calves as shown in Fig.12, with reduction in deformation equal to 32.86 % from using PCA materials rather than PP material. Maximum von – Misses stresses were 30.11 and 15.03 N/mm2 for PCA and PP materials as shown in Fig.13, and these values appears only in very small red regions near lower hole for strap fixation due to developing high stress concentration region around a hole. The actual maximum stress that have significant regions over calf's surface area were 6.72 and 10.04 N/mm2 for PCA and PP materials respectively, that means good reduction in stress was developed in PCA materials rather than PP one about 33.13 %.

Maximum factor of safeties for new and ordinary materials was 15 lowered to 5 around fixed upper and lower holes for straps, where orange regions for PP material has greater area than against new materials as shown in Fig.14. Higher cycles to fatigue (life) was achieved 1.0 x 107 cycles from using new material as shown in Fig.15 in comparison with only 2.3x 106 cycles to calf failure for ordinary material with increment in life reached more than four times. The effect of selecting different cut – out angles on fatigue items results can be shown in Table 3 using two additional angles 30o and 35o for calf by using new materials only.

In sole fatigue calculations, the maximum deformation of sole can be detected as shown in Fig.16-a on tip of forend sole region which equal to 7.305 x 10-4 mm, while maximum dynamic von –misses was concentrated at the forend of sole wall (C – section) and equal to 4140 N/m2 as shown in Fig.16-b. The maximum factor of safety was 15 while the overall life of new sole equal to 2.3 x 106 cycles as shown in Fig.16-c and 16-d respectively.

A most important item for present study of AFO and in general biomechanical applications in prosthesis and orthosis were represented by dorsiflexion angle and sole life, therefore comparison between experimental and theoretical results had been done; Table 3 represents this comparison with only 0.8 % and 7.1 % differences for dorsiflexion angle and sole life respectively.

5. Conclusion

The major points can be concluded from present work are being listed in following points :

1. The PCA materials which used as calf materials instead of PP material was increase the calf life from 2.3 x 106 to 1.0 x 107 cycles, in addition to good reduction in fatigue deformation and Von - Misses stresses was obtained tend to 33.86 and 33.13 % respectively.
2. Increasing in dorsiflexion angle was obtained in present paper from 7.7° in ordinary solid AFO to 8.2° in new AFO made from PCA and PP materials.
3. Approximately identical results have been obtained for dorsiflexion angle of a new design of orthoses between experimental angle (θexp. = 8.2°) using experimental images in dartfish program and theoretical angle (θtheo. = 8.266°) by using ANSYS program.

4. Experimental life of sole (2.137 x 106 cycles) while theoretical life (2.30 x 106 cycles) are investigated in present paper with good tendency of both results.
5. Dynamic factors of safety are higher than against static loading cases and its ranged between (5 – 15).

Nomenclature

AFO	Ankle Foot Orthosis
GRF	Ground reaction force
PCA	Perlon – Carbon fibre – acrylic
PP	Polypropylene

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