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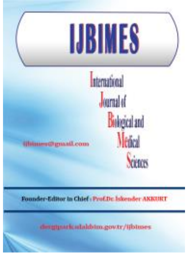

Research Article

Experimental and Computational Examination of the Bovine and Chicken Skins under Tensile Loading#

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Abstract: Skin characteristics are quite significant to develop new materials covering the hyper-elasticity, visco-elasticity or plasticity etc. To improve, especially distinguished composite structures vast type of materials are brought up together. However, just because of the reconstructive and safe elongation capability skin is one kind of the best examples. To clarify the mechanical properties of the skin, tensile test of different animal skins were carried out. To compare the stresses, strains and forces of skin while in the daily life movements, with the help of test results, tensile tests of different animal skins were simulated by the Finite Element Analysis (FEA). For the skin experiments, sample of bovine and chickens were utilized. The tensile test results and computer simulation results of animal skin samples were compared via the forces, stresses and also the differences between were indicated. The results of the study give considerable correlation between the tests and the numerical modeling of the skins. Simulation and test results are the supporting data and a reference guide for creating a numerical model in computer applications.

1. Introduction

The skin is a material that exhibits sophisticated behaviours. Today numerous studies are led to better understand living materials. Such works are used for different goals. Some are designed to deal with medical treatments [1], others to simulate surgical operations such as heart and vein [2]. Most of these studies are based on finite element models. A finite element model generally needs several assumptions to be performed, but in order to obtain reliable results; clearly defined steps need to be followed. First, the geometry must be as realistic as possible. Then, the mechanical behaviour needs to be as close as possible to the real behaviour. This can be obtained by in vivo (ultrasounds, IRM) or by in vitro measurements. Scientists usually show that even if in vitro studies are easier to perform they do not allow characterizing precisely both geometry and mechanical parameters [3].

Advances in biomechanics of the skin and computational methods have given a strong push forward in the mechanical simulation of procedures of modelling [4]. The Finite Element Modelling is the most common way to perform a skin biomechanics processes but it includes many type of modelling procedures. One of this type of modelling is three-dimensional (3-D) finite element modelling. Weiss et al, have researched the strategies for FE modelling of ligament mechanics and described technical aspects by differentiating between whole joint models and models of individual ligaments [5]. Song et al, have been calculated the force and stress distribution within the anteromedial (AM) and posterolateral (PL) bundles of the anterior cruciate ligament (ACL) in response to an anterior tibial load with the knee at full extension using a validated three-dimensional finite element model (FEM) of a human ACL [6].

The other modelling procedure which is used in FE modelling is ABAQUS software program. Bischoff et al, have aimed to explore the ability of ABAQUS computational model to simulate boundary value problems with a new orthotropic, hyperelastic constitutive law [7]. Using this kind of computational models to simulate such tests is quite widespread. A different computational model is also presented by Cavicchi et al, for the simulations of procedures of reconstructive surgery characterized by the excision of a cutaneous defect and the closure and suture of the wound edges [4]. Lapeer et al as well, have arrived at a prototype real-time simulator for plastic surgical interventions such as skin flap repair and inguinal herniotomy [8].

In addition, there is many type of modelling procedures using in finite element modelling. All these procedures assist to simulate the skin biomechanics and to understand what the story is about it. Human skin is a heterogeneous material composed of collagen and elastin fibres in a proteoglycan matrix. Acting together, these components are responsible for the mechanical behaviour of skin (Bischoff et al, 2000). Bischoff et al, have demonstrated in their research that a constitutive model derived from the statistical mechanics of long-chain molecules, corresponding to the fibrous collagen network in skin, captures the mechanical response of skin [9].

Human skin is the main organ of protection of the body against the external environment. One of its most essential functions is the protection against external mechanical aggressions, which is ensured by a reversible deformation of its structure. Mechanical testing of human skin presents considerable challenges in different domains. For example, measuring human skin mechanical properties contributes to quantification of effectiveness of dermatologic products or detection of skin diseases. Pailler-Mattei et al, have proposed a new method the human skin mechanical properties in vivo using the indentation test. In their study, human skin was assumed to behave elastically in the considered load range and the obtained results demonstrated that it is necessary to take into account the effect of the subcutaneous layers to correctly estimate the skin Young's modulus. All models in their research give an average value of the skin Young's modulus between 4.5kPa and 8kPa, these values are in good agreement with the literature [10-13].

Predicting the injury risk in automotive collisions is also requires accurate knowledge of human tissues, more particularly their mechanical properties under dynamic loadings. Jacquemoud et al, they have aimed to determine the failure characteristics of planar soft tissues such as skin, hollow organs and large vessel walls. This consists of a dynamic tensile test, which implies high-testing velocities close to those in automotive collisions. Their methodology has first been applied to human forehead skin and can be further expanded to other planar soft tissues. The failure characteristics for the skin in terms of ultimate stress are 3MPa and 71.5MPa. The ultimate global longitudinal strains are equal to 9.5% and 71.9% (Green Lagrange strain), which contrasts with the ultimate local longitudinal strain values of 24.0% and 75.3% (Green–Lagrange strain). This difference is a consequence of the tissue heterogeneity, clearly illustrated by the heterogeneous distribution of the local strain field [14].

For studying human skin, pig skin is one of the substitute material due to its similarity in material response to human skin [15,16]. Lim et al, they have performed the uni-axial tensile experiments on pig skin to investigate the tensile stress-strain response at both quasi-static and dynamic rates of deformation. The experimental results show that pig skin exhibits rate-sensitive, orthotropic and non-linear behaviour [17]. In this study, the mechanical properties of fresh frozen cow and chickens' freshly dissected skin specimens were determined by destructive tensile tests. Mechanical test results for specimens were evaluated and compared to the computer aided finite element analyses for the samples.

2. Method

To determine skin mechanical behaviours tensile tests and FEA were carried out in several experimental studies. Some of these studies have been performed to determine the material properties and force–deformation behaviours of the skin tissues under tensile loading. In this study, 9 cow and 10 chicken specimens for the tensile tests, cleaned from all soft tissue, were obtained from a local abattoir at Sakarya were used. See Fig. 1 for sample animal skins. The dimensions of the animal skins were shown in Table 1.

2.1. Tensile tests

Tensile tests were performed on each skin using a Zwick Z050 testing machine. See Fig. 2 for the tensile test machine setup. The jaws of the tensile test apparatus designed differently with teeth for gripping the skin without slipping because of its fats. Test starting point was set up to the skin, till

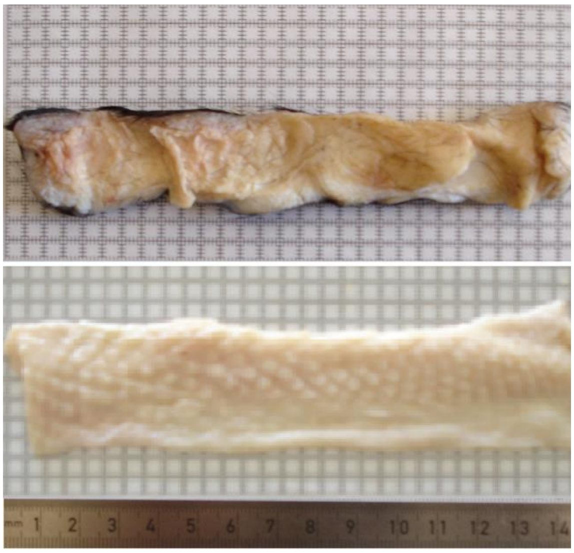


Figure 1. *Cow and chicken skin specimens.*

Figure 2. *The tensile test setup*

Table 1. Dimensions of the animal skins for tensile tests.

Animal Skin *Test Speed*	**Skin Number**	Width (mm)	Thickness (mm)	Distance between Jaws (mm)	Initial length (mm)
Cow Skin *0,5mm/s*	**1**	25	5	102	167
	2	16,5	4,1	123,7	170
	3	15	4,9	125,9	165
	4	16,5	4,6	112	170
	5	14,5	3,9	87,5	160
	6	16,7	5,5	90	165
	7	16	4,1	100	175
	8	16,8	3,9	95,9	170
	9	17,3	3,3	101,5	160
Chicken Skin *0,5mm/s*	**1**	18,6	2,2	69	-
	2	21	1,2	51,4	-
	3	17	1,2	60	-
	4	20,5	2,1	60	-
	5	18	2,1	68,3	-
	6	24,3	2,7	65,3	-
	7	17,7	1,6	58	-
	8	18,8	0,8	57,3	-
	9	25	1,7	41,4	-
	10	18,8	1,9	64,2	-

the softness of it was disappeared and any reaction force was taken from the load cell. The dimensions of the skin was taken in these conditions (Table 1).

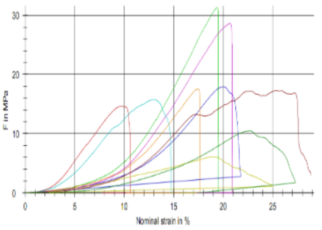
2.2. Finite element analysis

FEA models were created simply up to the dimensions taken from the skin and test setup. Element size was selected such as to provide a smooth mesh.

Finite Element Analysis were solved in ANSYS Workbench and were used to calculate prescribed displacements in the tests needed to obtain the stresses and strains. One sample static finite element analysis (FEA) was solved for each cow and chicken skin group. For tensile test, basic skin model's one side was fixed and the other side was forced by the moving press jaw. The FEA is based on a linear elastic material model (linear static analysis). The properties of skins were calculated from the tests. Finite Element Simulations were figured out under static conditions by giving real breaking point displacement to the one side of the skin. The force-displacement values were taken from the tests results of each selected skins.

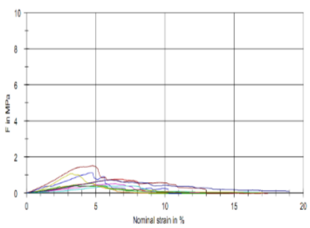
3. Results and Discussion

The mechanical properties of skin specimens were determined in destructive tensile tests to investigate the influence and mechanical behaviour and strength of the skins and to compare them to the static Finite Element Analysis with the help of load-cell. In this procedure reaction forces of skins and displacements are recorded by the computer. Test results and stress-strain curves of animal skins of each animal were shown in Fig.3. In cow skins, maximum strength was produced by the 2nd specimen and the value of it was 31,3MPa. For chicken skins, maximum stress was 1,5MPa. Skins should not be compared, because of being in different group of animals.



Nr	L_0 mm	b mm	h mm	A_0 mm²	E_t MPa	σ_M MPa	ε_{tM} %	σ_B MPa	ε_B %
1	397,69	25	5	125,00	8,82	14,7	9,7	8,82	11
2	402,10	16,5	4,1	67,65	7,81	31,3	19	31,3	19
3	402,31	15	4,9	73,50	8,90	17,9	20	3,59	22
4	389,13	16,5	4,6	75,90	10,1	17,5	17	17,5	17
5	364,03	14,5	3,9	56,55	10,0	28,6	21	28,6	21
6	366,19	16,7	5,5	91,85	6,62	15,7	13	8,73	15
7	375,29	16	4,1	65,60	2,38	6,05	19	1,21	25
8	371,25	16,8	3,9	65,52	1,76	17,3	25	3,47	29
9	376,67	17,3	3,3	57,09	2,80	10,5	23	2,09	27

cow skins



Nr	L_0 mm	b mm	h mm	A_0 mm²	E_t MPa	σ_M MPa	ε_{tM} %	σ_B MPa	ε_B %
1	343,22	18,6	2,2	40,92	6,16	0,773	6,8	-	-
2	324,65	21	1,2	25,20	11,9	0,416	3,5	-	-
3	331,81	17	1,2	20,40	17,8	1,14	4,7	-	-
4	332,12	20,5	2,1	43,05	6,83	0,516	4,7	-	-
5	340,55	18	2,1	37,80	5,91	0,514	6,4	-	-
6	338,28	24,3	2,7	65,61	2,68	0,394	7,4	-	-
7	329,84	17,7	1,6	28,32	5,66	1,06	3,3	-	-
8	329,84	18,8	0,8	15,04	24,5	1,50	4,8	-	-
9	312,77	25	1,7	42,50	4,24	0,420	3,5	-	-
10	335,40	18,8	1,9	35,72	6,16	0,716	6,0	-	-

chicken skins

Figure 3. *Tensile test results and stress-strain curves for cow and chicken skins.*

For the tensile tests, the stress calculated by the axial force which is divided by the cross-sectional area and the strain calculated by the axial displacement divided by initial length. See Equation 1 and 2.

$$\sigma = F/A \quad (1)$$

$$\varepsilon = \Delta l / l_0 \quad (2)$$

Where **σ** is stress, **ε** is strain, $\mathbf{E_t}$ is Young (Elastic) Modulus, **F** is force, **A** is cross sectional area, **b** is width of skin, **h** is thickness, **Δl** is axial displacement and $\mathbf{l_0}$ is initial length of skin. For the subscripts, **M** is ultimate (max.) point, **B** is break point. To understand the relationship between the test results and FEA, three different computational models, were solved in ANSYS with statically structural analysis conditions. The static mechanical test analyses were solved under the maximum force values that occurred during the real test procedures. Under these circumstances stress results were obtained. Stress distribution of skins were shown to determine the critical areas (Fig. 4). The observation of the results was helped to figure out that the differences were derived from the perfect FEA models, static simulation conditions. Because of different genetic algorithms similar size skins could be treated differently. But the results of the simulations were helpful for specimens under computational biomechanical studies.

4. Conclusions

The present study investigated the changes in forces and stresses of the different skins in tensile tests and determined the behaviour of skins under FEA conditions.

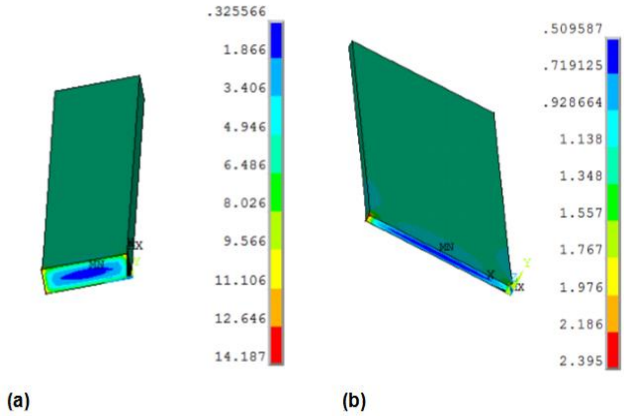


Figure 4. *Tensile test results for Equivalent Stresses of cow skin 4 (a) and chicken skin 8 (b).*

For further Finite Element Analysis of skins, skin stress-strain curves obtained and FEA procedures were generated.

The results of this study prove that in biomechanical studies investigating failure loads of different skins under tensile simulations, FEA models can be used.

The use of FEA helps simple computer simulations about biomechanical applications without making real tests.

Because of the use fresh frozen specimens of the animals are used like in vivo tests in biomechanical studies, investigating failure loads of skin by tensile tests and numerical analysis are guiding for surgery operations, biomechanical tests and computer simulations.

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