Research on the Behaviour of Cured Rubber to Physical Stress

ANA MARIA VASILESCU*, DEMETRA SIMION, DANIELA STELESCU
INCDTP – Division Leather and Footwear Research Institute, 93 Ion Minulescu Str., 031215, Bucharest, Romania

The paper presents experiments on developing new materials with preset properties for the footwear area, particularly for customized footwear. Research focused on analyzing a rubber plate formulation for heel tops commonly used in footwear manufacturing, varying the amount of filler and expanding agent in different proportions to obtain physico-mechanical properties appropriate for use. In this paper, the purpose of research was developing customized footwear by reducing the Fy mediolateral component of the ground reaction force when the foot touches the ground during walking. Developing customized footwear taking into account ground reaction force aims to improve walking or static position. In order to fulfill its role, footwear must reduce the Fy mediolateral component of the ground reaction force. Lately, reducing ground reaction force has been a major concern in footwear design and manufacturing. Ground reaction is measured using AMTI's AccuGait System force plate.

Keywords: cured rubber, customized footwear, ground reaction, force platform

Nowadays economic development is affected by the limited nature of some raw materials and energy, by the increasing demand of new materials with remarkable performance and application in various areas. This has led to the development of new materials with preset properties for the footwear area, particularly for customized footwear.

Developing customized footwear taking into account ground reaction force aims to improve walking or static position. Comfort or discomfort caused by the ground reaction force is expressed by the maximum value of the three components, namely: Fz vertical component, Fy mediolateral component and Fx anteroposterior component. These impact forces are shocks sent through the body, from heel to head through the skeletal structure. According to research in the last three decades, impact forces have been shown to be three times the body weight [1], leading to degenerative joint diseases, back pain, stress fractures, etc., and are influenced by the walking style, types of surfaces, design of the lower part of footwear and materials used in manufacturing.

In this paper, the purpose of research was to develop rubber mixtures with varying hardness in order to manufacture the customized shoe heel so that to reduce the Fy mediolateral component of the ground reaction force.

Experimental part

Processing natural and synthetic elastomers involves using numerous auxiliary materials having a well-established role in influencing properties of finished products or the selling price. In order to obtain products with well-determined physico-mechanical characteristics according to their destination, it is necessary to use various types of ingredients. A rubber plate formulation was chosen for experiments for heel tops, commonly used in footwear manufacturing, varying the amount of filler and expanding agent in different proportions to obtain physico-mechanical properties appropriate for use (table 1).

The following work method was used in compounding Duroflex rubber on roll:

- Rubber is added to the roll (1-2 mm) and mixed until it becomes easy to process (rubber plasticizing);
- ZnO, stearin, zinc stearate and colophony are added;
- 1/2 HAF, PEG and mineral oil are added;
- 1/2 HAF, paraffin and Ultrasil VN_3 are added and mixed until the compound becomes perfectly homogenous, at the temperature of 40^0C;
- antioxidant is slowly added and the mixture is cut until homogenization;
- roll temperature is lowered to room temperature and curing agents are added;
- porophor is slowly added and the mixture is refined.

Table 1
CURED RUBBER FORMULATIONS

No.	Rubber/raw material mixture, g	C 0	C1	C 2
1.	SIR natural rubber	500	500	500
2.	ZnO	17.5	17.5	17.5
3.	Stearin	10	10	10
4.	Zinc stearate	10	10	10
5.	Colophony	15	15	15
6.	Ultrasil VN_3	150	100	75
7.	PEG 4000	10	10	10
8.	Paraffin	10	10	10
9.	HAF carbon black	40	30	20
10.	Mineral oil	20	20	20
11.	IPPD antioxidant	10	10	10
12.	Sulfur	10	10	10
13.	DM	5	5	5
14.	D	2.5	2.5	2.5
15.	Porophor	0	20	25
16	**Total**	**790**	**750**	**720**

* *email: icpi@icpi.ro*

Table 2
MATERIALS AND ROLL PROCESSING TIME OF MATERIALS

No.	Order of adding ingredients	Time of adding the materials (minutes)
1.	Rubber	10
2.	ZnO + stearin + zinc stearate +colophony	4
3.	1/2 HAF+PEG+ mineral oil	8 - 10
4.	1/2 HAF+Ultrasil VN_3+paraffin	12
5.	IPPD	2
6.	Curing agents	5
7.	Expanding agent	3
8	Homogenization, refinement and taking off the roll	3 - 4
9	**Total**	**47 - 50**

The order of adding materials and roll processing time of the 14 mixtures are presented in table 2.

Laboratory experiments to develop cured rubber mixtures were performed on a cooling laboratory roll, with mixture processing capacity of about 4Kg.

Roll homogenization was done under the following conditions:

- Cylinder rotational speed: 24 r x mm;
- Temperature of rolls, as follows:
  1. Front roll: 30°C;
  2. Back roll: 24°C.

Temperatures were set so that the mixture would not overheat and the obtained sheet would be easily processed, without sticking to the rolls. Temperatures in the mixture sheet during roll mixing and after homogenization and refinement were determined using a pyrometer with penetrator.

The physico-mechanical properties of the two mixtures were determined and the test results are presented in table 3.

Quality control of cured rubber mixtures with and without expanding agent was performed using sheets pressed in matrices of 2 mm and 10 mm thickness, respectively. This stage takes place after the obtained sheets are pressed into plates.

In order to establish the optimal curing times, obtained mixtures were analyzed using the Monsanto rheometer at a temperature of 180°C, on the 100 scale, for 24 min.

In order to obtain plates to determine physico-mechanical properties, samples of the following sizes were taken from sheets:

- 150mm x 150 mm x 2mm;
- 80mm x 80mm x 6mm.

Plates were obtained in an electrical press, through the compression method, between its jaws, at a temperature of 180°C and time values, according to results of rheograms. In order to expand the material, dies were filled up to 75% of their capacity.

Stages and work conditions to obtain plates are the following:

- preheating with pressure of 1 Pa 3 min;
- pressing with pressure of 200 Pa 10 min;
- cooling with pressure of 200 Pa 5 min.

In the case of expanded plates, pressing parameters are important, as follows:

-180°C temperature was selected due to the fact that the expanding agent reacts to higher temperatures than that. Higher values were not used so that expansion would be uniform and with evenly-sized pores.

-Pressure also acts on the expansion method. Cooling was done in the die and at pressure so that not to deform the product.

-Die was filled up to 75% so that the product would be expanded.

After 24 h rest at room temperature, plates were subject to physico-mechanical determinations indicated in table 3.

Table 3
PHYSICO-MECHANICAL PROPERTIES OF CURED RUBBER MIXTURES

Physical-mechanical properties of rubber mixtures cured using expanding agent			
Rubber mixtures	C 0	C1	C2
Hardness °ShA	67	45	27
Density, g/cm^3	1.21	0.98	0.89
Abrasion strength, mm^3	198	280	320

Physico-mechanical characterization was performed according to standards in force, as follows:

• °ShA hardness - STAS 5441/3-1974 Cured elastomers. Determination of hardness in Shore A hardness degrees.

• Density, g/cm^3 STAS 5787-1992 Compact cured rubber. Determination of density.

Results presented in table 3 for Duroflex plates (fig. 1) lead to the following conclusions:

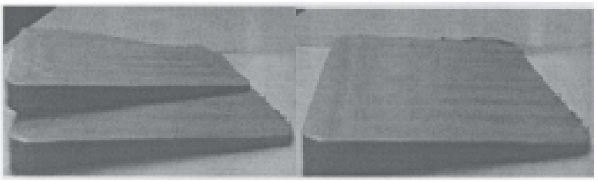

Fig. 1 Cured rubber plates

Shore hardness. Values of this characteristic vary in relation to reference values, which proves that the products contain less filler and are expanded. Experimental data prove that hardness decreases proportionally with the reduction of filler amount and with the increase of concentration of the expanding agent.

Wear resistance. Rubber wear is an essential parameter for the footwear industry and the rubber goods industry, as well as for technical rubber items used in the automotive industry. Its value increases by compounding rubber with expanding agents, exceeding normal parameters specific to Duroflex cured rubber (200-300 mm^3).

Footwear with customized heel constructed from heel tops (fig. 2) is manufactured according to the classic technology, as follows:

- punching the sole from the rubber plate (a);
- punching the heel tops from the rubber plate (b);
- making the heel by fixing heel tops using adhesive (c);
- making the heel top to which the heel cap made of two materials with different hardness is applied and with a 2-degree inclination so that by joining them a heel top is formed (d);

-Applying the heel cap by gluing;
-Pressing the heel;
-Dyeing the heel;
-Fixing the heel on the shoe.

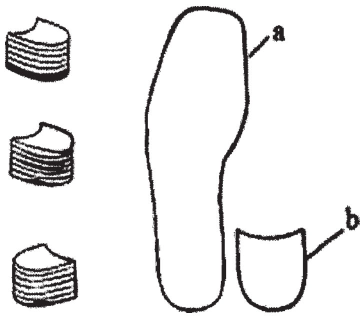

Fig. 2 Constructed sole and heel

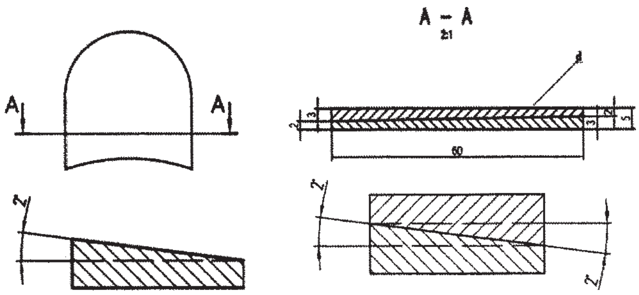

Fig. 3. Layered heel top, made of two beveled layers

The heel is made up of a series of heel tops (fig. 3), so that to obtain the appropriate heel height of the last. The heel tops are placed on top of each other and fixed by using adhesive.

The construction of this type of heels has the following advantages:

-Creating the customized heel according to the specific gait of each person;

-Simple construction;

- Low cost.

Hardness of the two materials varies depending on the walking style of each person.

The heel is made of several rubber layers, a layered heel top made of two beveled layers and a heel cap of thermoplastic rubber. Heel height and width may differ depending on the shoe model.

Results and discussions

In order to check the efficiency of the proposed solution, six shoe models with customized heel made of cured rubber plates with varying hardness were created, and to evaluate the three components of the ground reaction force, particularly the Fy mediolateral component, measurements were done using the AMTI force platform and BioAnalysis software, on four walking surfaces: carpet, linoleum, tar board and parquet.

Evolutions of the Fy mediolateral component for the six shoe models on each walking surface are presented in figures 4÷9.

The measurements performed using the AMTI force platform showed that the value of Fy mediolateral component varies depending on the hardness of cured rubber used in manufacturing the customized heel and on the walking surface.

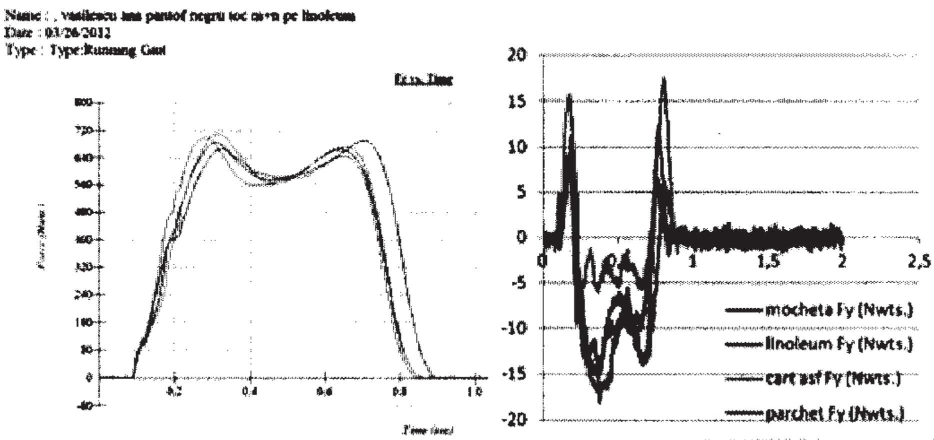

Fig. 4. Evolution of Fz vertical component and Fy mediolateral component of the ground reaction force during normal gait using shoe model 1 on the four surfaces

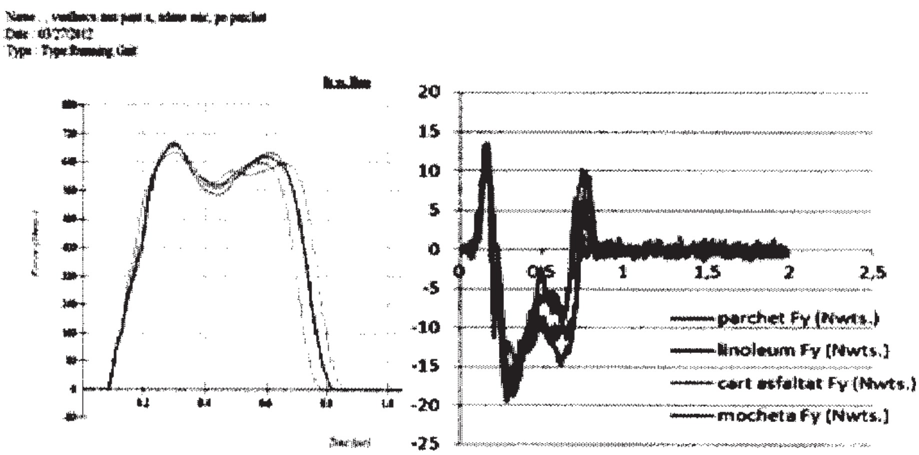

Fig. 5. Evolution of Fz vertical component and Fy mediolateral component of the ground reaction force during normal gait using shoe model 2 on the four surfaces

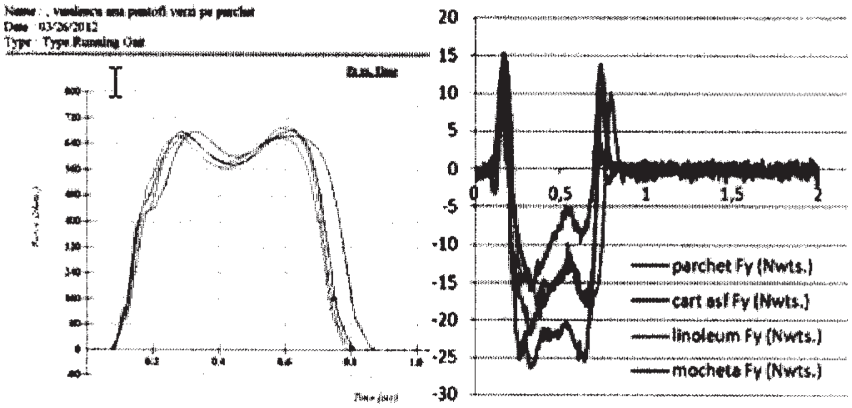

Fig. 6. Evolution of Fz vertical component and Fy mediolateral component of the ground reaction force during normal gait using shoe model 3 on the four surfaces

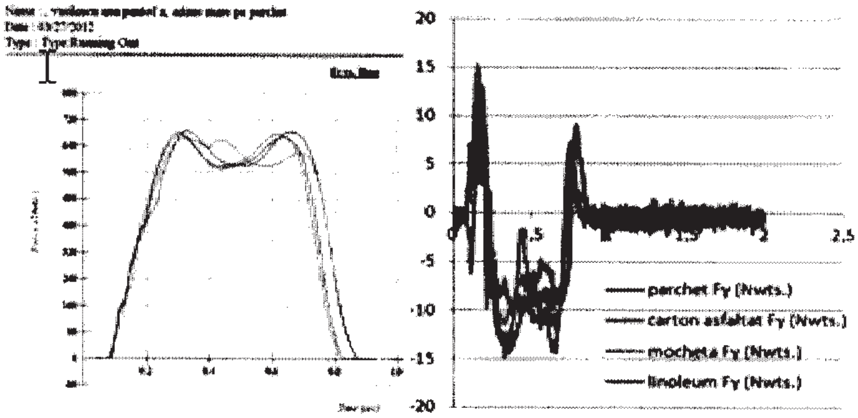

Fig. 7. Evolution of Fz vertical component and Fy mediolateral component of the ground reaction force during normal gait using shoe model 4 on the four surfaces

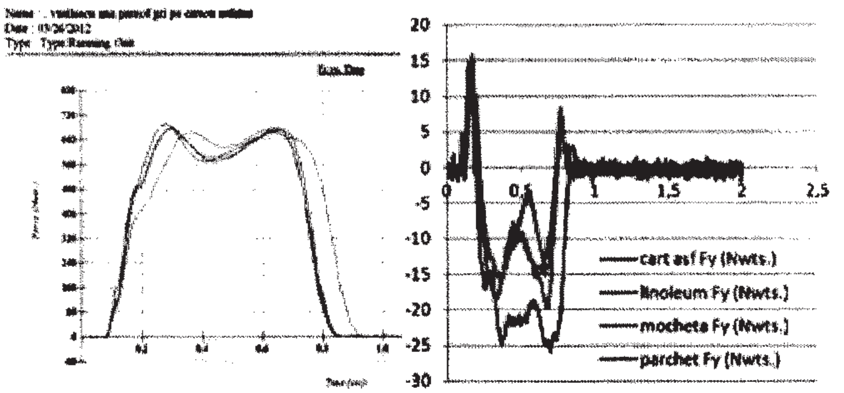

Fig. 8. Evolution of Fz vertical component and Fy mediolateral component of the ground reaction force during normal gait using shoe model 5 on the four surfaces

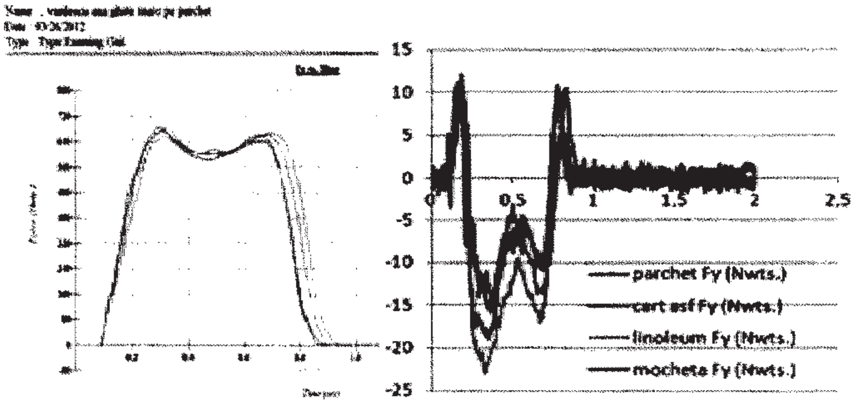

Fig. 9. Evolution of Fz vertical component and Fy mediolateral component of the ground reaction force during normal gait using shoe model 6 on the four surfaces

Conclusions

The paper presents the results of a study on obtaining cured rubber with varying hardness for manufacturing customized footwear. Thus, customized footwear must fulfill two basic characteristics:

- it must be custom made for each subject,
- it must be an instrument for prevention of anomalies.

This type of footwear is intended for wearers who do not exhibit structural or functional anomalies of the lower limb, but who value comfort in wearing to the detriment of other aspects, such as those related to heel height or shape.

References

1.JOSEPH HAMILL, 1996, Evaluating sport shoes using ground reaction force data , Biomechanics Laboratory –Department of Exercise Science -University of Massachusetts Amherst -Amherst –USA, ISSN 1999-4168, ISBS- Conference Proceedings Archive, 14 International Symposium on Biomechanics in Sports

2.JOANNA B. MORLEY, LESLIE M. DECKER, TRACY DIERKS, DANIEL BLANKE,JEFFREY A. French, and Nicholas Stergiou,2010, Effects of Varying Amounts of Pronation on the Mediolateral Ground Reaction Forces During Barefoot Versus Shod Running, Journal of Applied Biomechanics, 2, 205-214, © 2010 Human Kinetics, Inc.
3.ASTON J.W., CAROLLO, J.J., 1989, Normal Patterns of Walking and Running, in "Sport Medicine of the Lower Extremity", Subotnic S.I. (ed), Churchill Livingstone, New York
4.DIXON SHARON J. ; COLLOP ANDREW C. ; BATT MARK E. , 2000, Surface effects on ground reaction forces and lower extremity kinematics in running, Medicine and science in sports and exercise, ISSN 0195-9131, CODEN MSPEDA, vol. 32, n°11, p. 1919-1926 (23 ref.)
5.ANA MARIA VASILESCU, ANTON MICU, LUCIAN BOGATU, Experimental determinations of ground reaction force depending on characteristics of shoe sole materials and ground surface, COMEFIM 10 The 10-th International Conference on Mechatronics and Precision Engineering, 19-21, April 2011, Bucharest- Romania, U.P.B.Sci. Bull., Series D, Vol. 73, Iss.2, 2011
6.TEA MARASOVIC, MOJMIL CECIC, VLASTA ZANCHI, 2010, Analysis and Interpretation of Grand Reaction Forces in N ormal Gait, Laboratoty for Biomechanics and Control System, Faculty of Electrical Engineering Mechanical Engineering and Naval Architecture, University of Split, Croatia

Manuscript received: 2.08.2013