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A numerical investigation of mechanical behavior of unfilled styrene-butadiene rubber by static straight blade indentation

B. Setiyana[1,2,*], R. Ismail[1], J. Jamari[1], D.J. Schipper[2]

[1)] Laboratory for Engineering Design and Tribology, Department of Mechanical Engineering, University of Diponegoro, Jl. Prof. Soedharto, Tembalang, Semarang 59275, Indonesia.
[2)] Laboratory for Surface Technology and Tribology, Faculty of Engineering Technology, University of Twente, Drienerloolaan 5, Postbus 217, 7500 AE Enschede, The Netherlands.

[*]Corresponding e-mail: bsetiyana@yahoo.com

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ABSTRACT – By using Finite Element Analysis (FEA), this study investigated the indentation load and maximum stress due to straight blade indentation of unfilled Styrene Butadine Rubber. Results are presented as a function of blade indenter characteristics, wedge angle and tip radius, at a specified depth of indentation.

1. INTRODUCTION

Rubber indentation by a straight blade indenter is usually performed in a static as well as in a dynamic manner. McCharty et al [1, 2] investigated the blade sharpness by the static indentation to find the load at cut formation for various wedge angles and tip radii. Dynamic indentation by a straight blade is mostly conducted through sliding indentation or abrasion [3-5], with a result that there is a periodic wear pattern formed at the abraded rubber surface. Experimentally, Fukahori at al. [6] showed that the pattern spacing strongly depended on the hardness of the rubber.

There were two important parameters, i. e. the load at cut formation and the hardness of the rubber. It has been widely known that the force at cut formation depends on the ultimate stress of the rubber meanwhile the hardness complies with the rubber stiffness. These parameters depend on the mechanical behavior of the rubber and blade characteristics. It is difficult to describe accurately the mechanical behavior of the rubber theoretically, so it is most frequently modeled as a hyperelastic material through phenomenological methods. However, the hyperelastic model cannot describe the cut formation level, because, in general, the model is constructed up to a certain strain level which is lower than the ultimate strain at a crack or cut formation.

The aim of the present study is to investigate the mechanical behavior of a straight blade indentation on Unfilled Styrene Butadine Rubber (SBR-0) through FE analysis. The analysis is conducted for various wedge angles and tip radii of the blade indenter.

2. METHOD

The finite element analysis of the present work was performed using a commercial finite element software package, ABAQUS 6.11 [7] with a built-in strain energy function (SEF) model for a hyperelastic material. The SBR-0 (Unfilled Styrene Butadiene Rubber) with the Mooney-Rivlin strain energy function is used and the material is assumed as an incompressible material. The SEF data were adopted from Liang's experiment [8] obtained from a uniaxial tensile test up to 5.5 MPa stress and 300% strain.

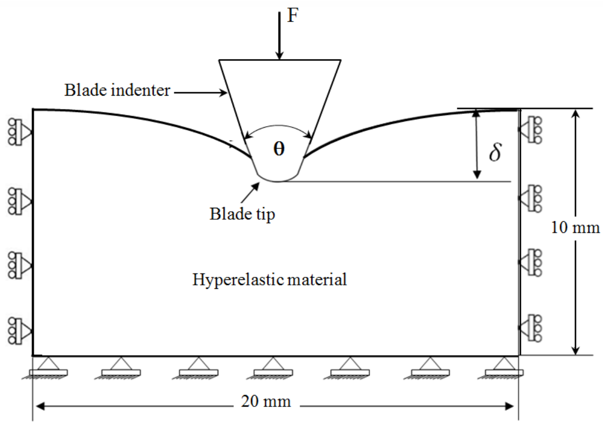

Figure 1 Schematic illustration of the indentation model; a rigid blade indenting a rubber surface.

Figure 1 shows a schematic illustration of a straight rigid blade indenting a rubber surface. Boundary conditions of the indentation system are depicted in this figure as well. The rubber material 10 mm height, 20 mm wide and 10 mm thick was modeled in plane strain. For analysis, the chosen blade wedge angle θ are 30, 45 and 60 degrees for a sharp blade (tip radius is 0 mm) which are often used in abrasion testing [3-6], and the chosen tip radii are 0.3, 0.4, 0.5 mm for a 45 degrees wedge angle.

The results are presented in the form of indentation load and maximum stress of the rubber at a specified blade displacement or depth of indentation (δ = 1 mm and 2 mm, see figure 1) for some various data of the blade indenter.

3. RESULTS AND DISCUSSION

Figure 2 demonstrates a FEA output of the von Mises stress distribution of SBR-0 by blade indentation with a 45 degrees wedge angle and 0.3 mm tip radius. The highest contact stress and deformation are located at the indenter's blade tip.

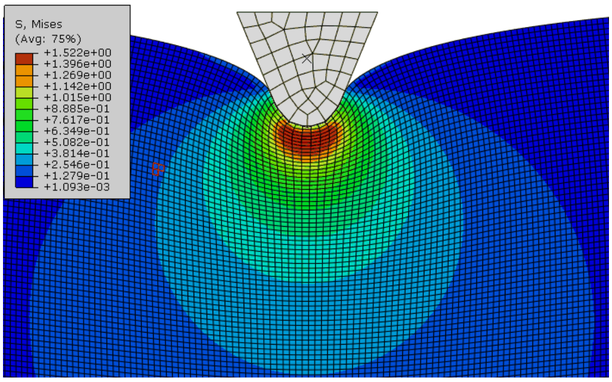

Figure 2 Example of FEA output; stress distribution of SBR-0 induced by blade indentation, δ = 1mm.

FE simulation shows that a quadratic relationship between the indenter load and the blade displacement is found. Consequently, there is a linear relationship between the rubber stiffness and blade displacement. Based on the specified blade displacement δ, Figure 3 and 4 show the relationship between indenter load and maximum stress as a function of the wedge angle and tip radius respectively.

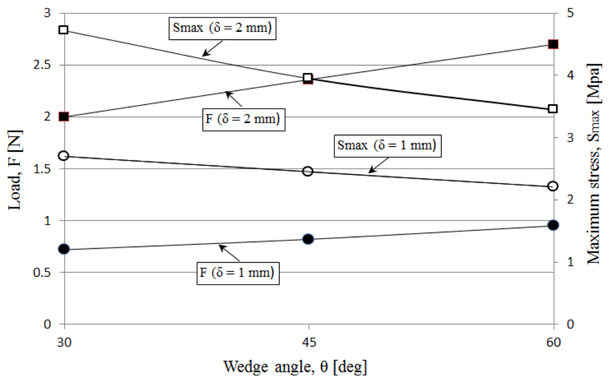

Figure 3 Indentation load and maximum stress for various wedge angles at sharp blade tip radius 0 mm.

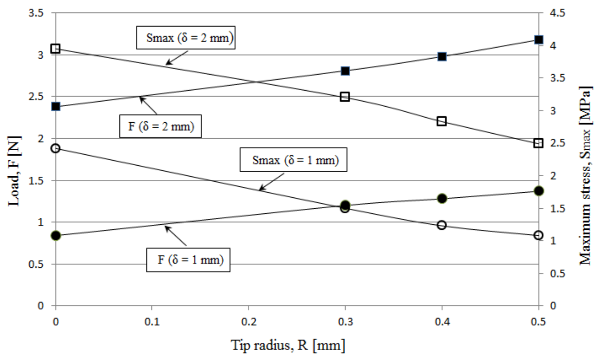

Figure 4 Indentation load and maximum stress for various blade tip radii for a wedge angle of 45 degrees.

These figures exhibit that the indenter load increases with increasing wedge angle and tip radius of the blade, meanwhile, the maximum stress reduces due to an increasing wedge angle and tip radius. In general, a linear relationship between the indenter load and the maximum stress with the blade characteristics is found.

Qualitatively, these results show the same trend as found for polyurethane indentation at cut formation [2]. Thus, based on the results obtained in this study, it is shown that the cut formation of rubber-like materials by blade indentation can be estimated by using the method presented in this study.

4. CONCLUSION

This study investigates the mechanical response of straight blade indentation on Unfilled Styrene Butadine Rubber by FE analysis. At a specified depth of indentation, the indenter load increases and the maximum stress reduces due to an increase in wedge angle and tip radius. In general, a linear trend between indentation load and maximum stress as well as wedge angle and tip radius is found. Further, these results indicate that the method presented can also be implemented in analyzing the cut formation of rubber-like materials by blade indentation.

5. REFERENCES

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