The modification of steel belt layer of airless tire for finite element analysis

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Abstract. The airless tire can be considered as composite structure since it composed of several components with different materials for desired performance. The three main components of airless tire are rubber tread, shear band and polymer spokes. The shear band composed of three complex steel belt layers and should be considered as a sub composite structure. The finite element method can be used in designing and development of airless tire. However the diversity of materials in each component including the complex sub structure resulted in complicating modelling and consuming analysis time. Thus, the large computational resources are required to analyse those components. In this research, the simplification of modelling and analysis of airless tire was attempted by modification of steel belt layers. The Mooney-Rivlin hyperelastic model was used to describe the material properties of tread and spoke. The constitutive model constants were obtained by tensile and compressive test according to ASTM D412 and D575 standards, respectively. The simplified belt, which was developed by homogenization approach, was integrated into shear band component. The airless tire model with modified steel belt layers can be used to reduce the model complexity and analysis time while yields accurate results.

1. Introduction
The non-pneumatic tires (NPTs) which are built by several components have excellent performance according to its construction. To develop tire performance, the finite element method is widely used to study tire behaviour in various condition. Jan and Vladimira [1] presented the different ways of replacement of steel cord belt into pneumatic tire model such as SHELL element [2], reinforcement bar (REBAR) element and homogeneous material. The orthotropic material with homogenization of belt layers has good response to the surrounding environment. Next, Korunovic et al. [3] had been performed the finite element method evaluate the pneumatic tire structure. The material modelling of tire reinforcements was concentrated. REBAR element with various constitutive models was compared. The Marlow model was found to be the most suitable. Moreover, the REBAR element was used to replace the steel cord belt into shear band of NPTs [4]. The deformation analysis of finite element model agreed well with the experiment. However, the great time and resource of computation by this model remain the severe problem. The simplified belt by homogenization approach can
integrate into shear band component. It can reduce the complex model and analysis time. The NPT which is developed the shear band can use under the rapid time. Particularly, this NPT model will be advanced in the future.

2. Experimental

The characteristic of NPT or airless tire, Tweel 12N16.5 SSL ALL TERRAIN, which is developed by Michelin is presented in Table 1. The Tweel airless tire has three main components. There are rubber tread, shear band and polymer spoke (Fig. 1). The tire stiffness testing was performed to investigate the tire stiffness of Tweel airless tire. The airless tire was mounted at the mounting arm of tire stiffness tester (EKTRON TEK model: PL-2003). The compressive force and tire vertical deformation was recorded while the measurement table was moved and compressed the tire. The compressive load of 1000 kg was applied in this study. The experimental result was indicated that the vertical stiffness of airless tire which was studied is 949.37 N/mm.

| Tire Size (inch) | Tire Dimension (mm) | Weight (kg) |
|-----------------|---------------------|-------------|
| 12N16.5         | Width 309 OD 860    | 100         |

Table 1 The characteristic of airless tire model: Tweel 12N16.5 SSL ALL TERRAIN

![Figure 1](image1.png) Figure 1. The airless tire model: Tweel 12N16.5 SSL ALL TERRAIN.

![Figure 2](image2.png) Figure 2. The tire stiffness testing of airless tire.
2.1. Finite element method
The computer aided design (CAD) and computer aided engineering (CAE) was use to create the 3D finite element model of Tweel airless tire. The finite element model of steel belt layer is developed according to the Tweel airless tire which has a complex shear band construction as shown in figure 3. The shear band of finite element model composed wall and belt elements. The tread material property of airless tire model was investigated by compression test according to ASTM D575 standard, while material property of spoke was investigated by tensile test according to ASTM D412 standard, respectively. The tread, wall and spoke properties were defined by Mooney-Rivlin hyperelastic model. On the other hand, the steel belt is specified to be an elastic isotropic material as described in table 2. The airless tire model was compressed with the compressive load of 1,000 kg. This simulation performs by moving the rigid plate to press airless tire model according to the testing of tire stiffness tester (Figure 4).

Table 2 The material properties of airless tire model

| Components      | Mooney-Rivlin constant | Young’s Modulus (GPa) | Poisson’s Ratio |
|-----------------|------------------------|-----------------------|-----------------|
|                 | C10                    | C01                   |                 |
| Tread           | 1.19085                | 0                     | -               |
| Wall            | 1.19085                | 0                     | -               |
| Steel Belt      | -                      | -                     | 200             | 0.3             |
| Spoke           | 0.5063                 | 4.2552                | -               |

3. Results and discussion
The compressive load and vertical deformation of airless tire model was recorded while the airless tire model is compressed by rigid flat plate. The simulation result has a good agreement with the experimental result (EXP) from tire stiffness testing. The comparison of simulation model and experiment is presented in Figure 5. The result of using homogenization approach with isometric material different as the result of using REBAR element to replace the steel belt as shown in Figure 5. The vertical stiffness of airless tire finite element model by using homogenization approach and REBAR element were 905.77 N/mm and 814.93 N/mm, respectively. The summary of simulation result is described in Table 3.

![Figure 3](image_url) The cross section shear band of (a) Tweel airless tire and (b) airless tire model.
Figure 4. The finite element model of compressed airless tire.

Figure 5. The vertical deformation and compressive load of compressed airless tire.

Table 3 Summary of simulation result.

| Model                     | Simulation Time (min) | Error (%) |
|---------------------------|-----------------------|-----------|
| REBAR element [4]         | 40                    | 14.16     |
| Homogenization approach   | 45                    | 4.59      |

4. Conclusions
The modification of steel belt layer in shear band of airless tire model by homogenization approach with isotropic material provided more accurate result than model by REBAR element approach when compared to the experiment. The analysis time was also found to not significantly increase and can be neglected. The airless tire model with modified steel belt layers, which the rubber part was specified by hyperelastic material property, can be used to reduce the model complexity and analysis time while yields accurate results.

5. References
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