INTISARI

Kampas rem sangat penting dalam sistem pengereman otomotif, karena berfungsi untuk mengontrol, memperlambat, dan menghentikan laju kendaraan. Kampas rem asbestos dilarang digunakan karena menghasilkan debu yang berbahaya terhadap lingkungan dan kesehatan. Penelitian ini bertujuan untuk mendesain dan membuat kampas rem non-asbestos organik (NAO) sebagai pengganti kampas rem asbestos. Empat komponen utama bahan penyusun kampas rem NAO, yaitu pengikat, pengisi, penguat, dan *friction modifier* dikaji masing-masing dengan memvariasikan komposisinya. Komposisi yang menghasilkan kinerja gesekan dan keausan optimum dijadikan formula baru kampas rem NAO.

Penelitian ini diawali dengan menvariasikan fraksi volume *phenolic resin* sebagai pengikat. Variasi fraksi volume yang dipilih yaitu 10, 15, 20, dan 25%. Bahan pengisi merupakan kombinasi antara $BaSO_4$ dan *friction dust*. Variasi fraksi volume $BaSO_4$ terhadap *friction dust,* yaitu 30:0%, 25:5%, 20:10%, 15:15%, dan 10:20%. Bahan penguat merupakan kombinasi antara serat *rockwool, cellulose,* dan PAN. Rasio komposisi serat *rockwool*: *cellulose*: PAN yang digunakan adalah 6:4:8% vol, 8:4:6% vol, 10:4:4% vol, dan 12:4:2% vol. Pemilihan parameter komposisi bahan *friction modifiers*, selanjutnya didesain menggunakan metode Taguchi. *Orthogonal array* (L_8) yang terdiri dari 5 faktor terkontrol (grafit, MoS_2, h-BN, Al_2O_3, dan SiO_2) dipilih dan masing-masing faktor terdiri dari 2 level. Parameter komposisi optimal yang menghasilkan kinerja gesekan dan keausan yang terbaik dijadikan sebagai formula baru kampas rem NAO. Pembuatan sampel dimulai dengan menimbang berat untuk masing-masing komposisi. Berat campuran dicampur selama 60 menit. Campuran serbuk dikompaksi ke dalam cetakan panas dengan tekanan 47 MPa pada temperatur 150 °C selama 15 menit. Sampel diproses *postcuring* pada temperatur 150 °C selama 6 jam. Sampel diuji densitas, kekerasan Shore-D (H_D) dan *Rockwell S-scale* (HRS), porositas, stabilitas panas (TG/DTA), koefisien gesek, dan keausan. Pengujian koefisien gesek dan keausan dilakukan dengan mengacu pada standar SNI 09-0143-1987 dan SAE J661. Morfologi permukaan aus sampel selanjutnya dianalisis dengan EDS dan pengamatan SEM.

Nilai koefisien gesek dan keausan spesifik rata-rata untuk fraksi volume *phenolic resin* 20% masing-masing sebesar 0,43 dan 0,905 x 10^{-7} cm^3/N.m. Koefisien gesek dan keausan spesifik pada *phenolic resin* 25% vol sebesar 0,3 dan 0,58 x 10-7 cm^3/N.m. Rasio komposisi $BaSO_4$: *friction dust* (20:10% vol) menghasilkan kinerja gesekan optimum, dengan nilai kinerja *fade II* rendah (4,88%), kinerja *recovery II* tinggi (113,69%), dan stabilitas koefisien gesek paling tinggi (91,25%). Rasio kombinasi serat *rockwool*, *cellulose*, dan PAN (10:4:4% vol) menghasilkan kinerja gesekan dan keausan yang optimum dengan nilai kinerja koefisien gesek (μp: 0,49); fluktuasi koefisien gesek (0,13); stabilitas dan variabilitas koefisien gesek masing- masing sebesar 0,89 dan 0,24; kinerja *fade* (12,36%); kinerja *recovery* (112,24%), dan kehilangan berat dan tebal masing-masing sebesar 7,83% dan 7,34%. Bahan *friction modifiers* yaitu pelumas padat (grafit, h-BN, dan MoS_2) memberikan pengaruh yang dominan terhadap kinerja gesekan dan keausan dibandingkan bahan abrasif (Al_2O_3 dan SiO_2). Formula baru kampas rem terdiri dari campuran *phenolic resin* 25% vol, $BaSO_4$ 20% vol, *friction dust* 10% vol, penguat serat (*rockwool* 10% vol, *cellulose* 4% vol, dan PAN 4% vol), *friction modifiers* (grafit 8% vol, h-BN 2% vol, MoS_2 4% vol, Al_2O_3 2% vol, dan SiO_2 3% vol), tembaga 5% vol, dan MgO 3% vol. Formula baru ini menghasilkan kinerja *fade* (12,48%); kinerja *recovery* (122,58%); stabilitas koefisien gesek 81,82; fluktuasi koefisien gesek 0,14; kinerja koefisien gesek 0,406; dan keausan (kehilangan berat 5,36% dan tebal 5,45%).

Kata kunci: non-asbestos organik, kampas rem, koefisien gesek, kinerja *fade-recovery*

ABSTRACT

Brake pads are very important in the automotive braking system. They function to control, reduce, and stop the vehicle. Asbestos brake pads are prohibited to use because they produce dust, which is harmful to the environment and health. This study aims to design and manufacture NAO brake pads as a substitute for asbestos brake pads. The four main components of NAO brake pad ingredients, namely binder, filler, reinforced, and friction modifiers were studied by varying their composition, respectively. The optimum result of the friction and wear performances was used as a parameter for the new formulation of NAO brake pads.

This research was initiated by varying the volume fraction of phenolic resin as a binder. The variations of volume fraction were selected of 10, 15, 20, and 25%. The filler material was a combination of $BaSO_4$ and friction dust. The volume fraction of $BaSO_4$ to friction dust was 30:10%; 25:5%; 20:10%; 15:15%, and 10:20%, respectively. Reinforce material was a combination of rockwool, cellulose, and PAN fibers. The composition ratio of rockwool: cellulose: PAN fibers was 6:4:8% vol, 8:4:6% vol, 10:4:4% vol, and 12:4:2% vol. Furthermore, the selection of parameters friction modifiers was designed using Taguchi Method. Orthogonal array (L_8) which consists of 5 factors (graphite, MoS_2, h-BN, Al_2O_3, and SiO_2) was selected with each factor consisting of 2 levels. The optimal parameters of friction and wear performances were used as a new formulation of NAO brake pads. The manufacturing of the sample begins by weighing the composition of each material. The weight of the mixture composition was then mixed for 60 min. The powder mixture was compacted into a mold under pressure 47 MPa and heated at the temperature of 150 °C for 15 min. Furthermore, samples were post-cured at a temperature of 150 °C for 6 hours. Samples were tested for density, hardness, porosity, heat stability, friction coefficient, and wear. The friction coefficient and wear were tested according to SNI-09-0143-1987 and SAE J661 standard. The worn surface morphology of the sample was then analyzed by EDS and SEM.

The study results show that the average friction coefficient and specific wear on 20 vol.% phenolic resin are 0.43 and 0.905 x 10^{-7} cm^3/Nm, respectively. Meanwhile, the friction coefficient and specific wear of 25 vol.% phenolic resin are 0.3 and 0.58 x 10^{-7} cm^3/Nm, respectively. The composition ratio of $BaSO_4$ to friction dust (20:10 vol.%) results in the optimum of friction performances i.e., the lowest fade II performance (4.88%), the recovery II performance (113.69%), and the highest friction stability (91.25%). The composition ratio of rockwool, cellulose, and PAN fibers (10:4:4 vol.%) results in optimum friction and wear performances. This composition ratio shows CoF performance (μp=0.49), CoF fluctuation (0.13), CoF stability and variability of 0.89 and 0.24, fade performance (12.36%), recovery performance (112.24%), and wear (weight loss is 7.83% and thickness loss is 7.34%). The friction modifier for solid lubricants (namely graphite, h-BN, and MoS_2) has a dominant influence on the friction and wear performances compared to the abrasive material (Al_2O_3 and SiO_2). The new formulation of the NAO brake pad consists of phenolic resin (25 vol.%), $BaSO_4$ 20 vol.%, friction dust 10 vol.%, fiber reinforcement (rockwool 10 vol.%, cellulose 4 vol.%, PAN 4 vol.%), friction modifiers (8 vol.% graphite, 2 vol.% h-BN, 4 vol.% MoS_2, 2 vol.% Al_2O_3, and 3 vol.% SiO_2), 5 vol.% copper, and 3 vol.% MgO. This new formulation results in fade performance (12.48%), recovery performance (122.58%), CoF stability (81.82), CoF fluctuation (0.14), and CoF performance (0,409).

Keywords: non-asbestos organic, brake pad, friction coefficient, fade-recovery performance.