INTISARI

Pengembangan sumber energi baru dan terbarukan termasuk pembangkit listrik tenaga panas bumi terus tumbuh berkembang. Selama beroperasi, PLTPB menghasilkan lumpur dengan kandungan silika di atas 50%. Sementara itu, industri pengolahan karet banyak menggunakan silika sebagai filler penguat. Akan tetapi, kandungan bahan pengotor, ukuran partikel serta kecenderungan silika untuk membentuk aglomerat dapat mempengaruhi kualitas produk karet yang dihasilkan. Penelitian ini bertujuan untuk mensintesis *nanoparticles geothermal silica* dari lumpur PLTP, menginvestigasi interaksi silika hasil sintesis pada kompon karet sebagai filler penguat serta mempelajari kinetika vulkanisasi karet dengan penambahan silika. Sintesis silika dilakukan dengan metode sol-presipitasi dengan mereaksikan lumpur kering dengan natrium hidroksida, dilanjutkan dua tahap penambahan asam sulfat pada natrium silikat dan silanisasi. Nilai pH divariasikan antara 7-9, suhu 70^{o}C-90^{o}C, rasio natrium silikat dan waktu aging 1-5 hari. Hasil penelitian menunjukan bahwa sintesis nanoparticles geothermal silica berhasil dilakukan dengan hasil TEM dan BET menunjukan ukuran partikel primer antara 5-10 nm dan luas permukaan 101,75-168,35 m^2/g. Hasil pengujian XRF dan XRD memberikan hasil kemurnian silika mengalami kenaikan menjadi 99% dengan struktur amorf. Sedangkan penerapan pada karet dilakukan melalui proses komponding dan vulkanisasi dengan variasi waktu, jumlah silika antara 0-40 phr, jenis silika serta metode silanisasi. Nanoparticles geothermal silica jenis NGS3 dengan penambahan 30 phr memberikan interaksi filler-karet terbaik berdasarkan dari pengujian karakteristik vulkanisasi, mekanik dan thermal yang didukung pengujian rating dispersi filler, *bound rubber content*, SEM serta *crosslink density*. Silanisasi silika memberikan kenaikan pada nilai *chemical bound rubber content* 15,73% menjadi 66,49% yang menunjukan perbaikan interaksi antara filler dengan karet. Perhitungan kinetika reaksi menunjukan jika interaksi filler-karet yang ditunjukan melalui bound rubber content dapat mengurangi mobilitas reaktan sehingga mempersulit reaksi vulkanisasi. Reaksi vulkanisasi yang didekati dengan model usulan memberikan gambaran reaksi reversi yang belum dapat diberikan oleh model Deng-Isayev.

Kata kunci: lumpur geothermal, nanoparticle silica, karet, filler penguat, interaksi

ABSTRACT

The development of new and renewable energy sources, including geothermal power plants, continues to grow. During operation, geothermal power plants generate sludge with a silica content of over 50%. Meanwhile, the rubber industry widely uses silica as a reinforcing filler. However, the presence of impurities, particle size, and the tendency of silica to form agglomerates can affect the quality of the resulting rubber products. This study aims to synthesize geothermal silica nanoparticles from geothermal sludge, investigate the interaction of the synthesized silica in rubber compounds as a reinforcing filler, and study the vulcanization kinetics of rubber with the addition of silica. The silica synthesis was carried out using the sol-precipitation method by reacting dried sludge with sodium hydroxide, followed by two stages of sulfuric acid addition to sodium silicate, and silanization. The pH varied between 7-9, the temperature was between 70 °C and 90 °C, the sodium silicate ratio and aging time varied from 1-5 days. The results showed that the synthesis of geothermal silica nanoparticles was successful, with TEM and BET results indicating a primary particle size of 5-10 nm and a surface area of 101.75-168.35 m^2/g. XRF and XRD analysis showed that the silica purity increased to 99% with an amorphous structure. The application in rubber was conducted through compounding and vulcanization processes with variations in time, silica content between 0-40 phr, silica type, and silanization method. The NGS3 geothermal silica nanoparticles with 30 phr addition yielded the best rubber-filler interactions results regarding vulcanization, mechanical, and thermal characteristics, supported by filler dispersion rating, bound rubber content, SEM, and crosslink density analysis. Silanization of silica increased the chemical-bound rubber content by 15.73% to 66.49%, indicating improved interaction between the filler and rubber. Kinetic calculations showed that filler-rubber interaction, as bound rubber content indicates, could reduce reactant mobility, thus hindering the vulcanization reaction. The vulcanization reaction modeled using the proposed approach revealed an inversion reaction that the Deng-Isayev models could not capture.

Keyword: geothermal sludge, nanoparticles silica, rubber, reinforcing filler, interaction