

## INTISARI

*Friction Stir Welding* (FSW) merupakan salah satu teknik pengelasan padat (*solid state welding*) yang berpotensi menjadi solusi untuk menyambung logam dengan konduktivitas termal yang tinggi, titik leleh relatif rendah, rentang suhu pembekuan luas, kecenderungan kuat teroksidasi, serta viskositas cairan rendah, seperti paduan magnesium AZ31. Kualitas sambungan FSW sangat dipengaruhi oleh parameter proses, terutama geometri pin yang menentukan aliran material dan distribusi panas selama pengelasan. Namun demikian, sambungan FSW pada AZ31 masih dapat menghasilkan tegangan sisa dan distorsi yang berpotensi menurunkan kualitas sambungan dan ketahanan perambatan retak fatik sehingga diperlukan perlakuan pasca-las untuk mengendalikannya. Oleh karena itu, penelitian ini bertujuan mengurangi tegangan sisa dan distorsi sekaligus meningkatkan sifat mekanik (kekerasan dan kekuatan tarik) serta ketahanan laju perambatan retak fatik sambungan FSW pada paduan magnesium AZ31 melalui variasi geometri pin dan variasi perlakuan pasca-las.

Penelitian dilakukan dengan memvariasikan pin dengan empat geometri pin yang berbeda yakni silinder, persegi, konus, dan segitiga. Berdasarkan hasil tahap pertama, geometri pin dengan performa mekanik terbaik dipilih untuk tahap berikutnya, yaitu studi perlakuan pasca-las yang meliputi kondisi tanpa perlakuan (*as welded*), perlakuan TTT, perlakuan *rolling* (PWDR), serta kombinasi antara TTT dan PWDR (PWTRT). Proses pengelasan FSW dilakukan pada kecepatan pengelasan konstan 30 mm/menit dengan kecepatan putaran sebesar 1500 rpm pada sudut kemiringan 2°. Evaluasi dilakukan melalui pengamatan mikrostruktur, kekerasan mikro *Vickers*, uji tarik, pengukuran distorsi, serta uji perambatan retak fatik.

Hasil penelitian menunjukkan bahwa sambungan dengan sifat mekanis terbaik pada tahap variasi pin diperoleh pada penggunaan geometri pin persegi. Geometri ini menghasilkan kombinasi masukan panas dan aliran material yang lebih optimal serta peran esentrisitas dari bentuk pin. Pada tahap perlakuan pasca-las, perlakuan kombinasi PWTRT memberikan peningkatan sifat mekanis paling signifikan dibandingkan kondisi lainnya. Hal ini disebabkan oleh peran TTT dalam *recovery* dan rekristalisasi statis serta perlakuan *rolling* memberikan deformasi plastis tambahan sehingga sinergisitas keduanya menghasilkan peningkatan kekuatan, kekerasan, serta ketahanan fatik sambungan FSW AZ31.

**Kata kunci:** *Friction Stir Welding* (FSW), AZ31, geometri pin, perlakuan pasca-las, TTT, PWDR, PWTRT, kekerasan, kekuatan tarik, perambatan retak fatik.

## ABSTRACT

Friction Stir Welding (FSW) is a solid-state welding technique with the potential to be a solution for joining metals with high thermal conductivity, relatively low melting points, a wide freezing (solidification) temperature range, a strong tendency to oxidize, and low fluid viscosity, such as AZ31 magnesium alloy. The quality of FSW joints is strongly determined by process parameters, particularly pin geometry, which governs material flow and heat distribution during welding. Nevertheless, FSW joints in AZ31 can still generate residual stresses and distortion, which may reduce joint quality and fatigue crack propagation resistance, so post-weld treatments are required to control these issues. There fore, this study aims to reduce residual stresses and distortion while improving the mechanical properties (hardness and tensile strength) and fatigue crack growth resistance of FSW joints in AZ31 magnesium alloy through variations in pin geometry and post-weld treatment conditions.

The study was conducted using four different pin geometries: cylindrical, square, conical, and triangular. Based on the results of the first phase, the pin geometry with the best mechanical performance was selected for the next phase, a post-weld treatment study that included untreated conditions (as welded), TTT treatment, rolling treatment (PWDR), and a combination of TTT and PWDR (PWTRT). The FSW welding process was carried out at a constant welding speed of 30 mm/min with a rotational speed of 1500 rpm and a 2° tilt angle. Evaluation was conducted through microstructural observations, Vickers microhardness, tensile tests, distortion measurements, and fatigue re-propagation tests.

The results showed that the joint with the best mechanical properties in the pin variation stage was obtained using a square pin geometry. This geometry provides an optimal combination of heat input and material flow, as well as the eccentricity of the pin shape. In the post-weld treatment stage, the PWTRT combination treatment provided the most significant improvement in mechanical properties compared to the other conditions. This is due to the role of TTT in recovery and recrystallization, and the rolling treatment providing additional plastic cooling. The synergy of the two treatments results in increased strength, hardness, and fatigue resistance of the AZ31 FSW joint.

**Keywords:** Friction Stir Welding (FSW), AZ31, pin geometry, post-weld treatment, TTT, PWDR, PWTRT, hardness, tensile strength, fatigue crack propagation.