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論　文　要　旨　(博士)

論文題目	摩擦攪拌援用アルミニウム合金/鉄鋼材突合せ接合体創成法の確立および接合機構の解明

(要旨　1,200 字程度)

近年，地球温暖化対策とする省エネルギー化の観点から，自動車，航空機，鉄道車両，船舶等の輸送機器の分野において燃費の向上を目的とした軽量化が強く求められており，それら機器への軽量部材，特にアルミニウム合金の適用が積極的に進められている．しかし，輸送機器全体をアルミニウム合金で構成することは一般的に，強度・生産コストにおいて困難である．そこで，高強度且つ軽量な構造体として，強度を必要とする部分には高強度な鉄鋼材料を適用し，強度を必要としない部分には軽量なアルミニウム合金を適用した Fe/Al ハイブリッド構造体が期待される．また，その構造体の作製にあたり，アルミニウム合金と鉄鋼材料の接合が必要不可欠である．現在，この接合にはロウ付けや機械的結合が用いられることが多いが，これらは機械的浄土や重量面，生産性に問題を抱えている．また，一般的な接合法として知られている溶融溶接を鉄鋼材料とアルミニウム合金に適用した場合，接合海面にもろい金属間化合物が厚く形成され，強固な接合部を得ることが困難とされている．

この問題に対して，近年アルミニウム合金同士の接合法として普及しつつある摩擦攪拌接合法(Friction Stir Welding : FSW)に着目した．摩擦攪拌接合法とは，専用の回転ツールを被接合材料に挿入し，回転ツールと被接合材料間の摩擦熱で材料を加熱・軟化させ，材料を回転ツールで攪拌して塑性流動させることによって被接合材料間を接合する技術である．近年では，摩擦攪拌作用によるアルミニウム合金/鉄鋼材料のスポット接合体の創製が可能であることが報告されている．

本研究では，摩擦攪拌作用によるアルミニウム合金/鉄鋼材料の突合せ接合の可能性を調査するとともに，その接合メカニズムを明らかにすることを目的とした．

本論文では，先ず，接合ツール先端のプローブ側面を鉄鋼材料に接触させ，ツール回転方向と接合方向が一致する側に鉄鋼材料を配置することによって，摩擦攪拌作用によるアルミニウム合金/鉄鋼材料間の接合体創製が可能であることを明らかとした．次に，接合体の特性に影響を与える要因として，接合条件(接合ツール形状，ツール回転数，接合速度)を変化させて接合を行い，それらが接合強度に与える影響を明らかにした．また，接合部界面を詳細に観察することにより，接合部界面に Fe/Al 間金属間化合物が生成することで接合が行われていることを明らかにした．さらに，アルミニウム合金の流動状態の模擬として，透明塩化ビニルによる直接観察を行い，ツール先端の温度分布，垂直荷重，水平荷重の計測及び，有限要素法によるアルミニウム合金の応力分布，ひずみ分布から，接合部の形成メカニズムを明らかにした．

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Abstract

Title	Butt welding between aluminum alloy and steel by friction stirring and elucidation of welding mechanism

(800 words)

Recently, the application of aluminum alloy which is a typical lightweight material has been expected to achieve energy saving in transportation vehicles. Generally, the structure made of only aluminum is low strength and high cost. Then, hybrid structure made of aluminum alloy and high strength materials like steel is promising to achieve both lightweight and high strength. For making the hybrid structure, it is necessary to weld aluminum alloy and steel. At present, the brazing and mechanical uniting are used in this joining. However, these processes have some problems such as mechanical strength, heavy weight and low productivity. Moreover, conventional fusion welding, like TIG or MIG, is difficult to be applied at the joining of dissimilar metals due to the formation of thick fragile intermetallic compounds in the weld interface.

To solve the above-mentioned problems, the friction stir welding that is spreading for welding of aluminum alloys is attractive. The friction stir welding is the technique that welds aluminum alloys in the solid state. Principles of friction stir welding are that weld materials are heated and soften by friction heat that occurs between rotating tool and weld materials. Then, softening weld materials are stirring by rotation of a tool.

The objective of this study is to investigate the possibility of butt welding of dissimilar materials by friction stirring and to clarify the welding mechanism in this process.

At first, the effect of the rotating tool position on the weld interface and rotating direction of the tool at butt welding of aluminum alloy and steel by friction stirring were investigated. Some effects from welding conditions were clarified by tensile test, bending test and corrosion test. Welding conditions such as the rotating speed of the tool, welding speed and tool shape were changed. In these welding conditions, the tool shape was most influence for formation of the internal defects and the welding strength. The joint fabricated by a welding tool with a screw probe exhibited superior tensile properties. From observation of weld line at aluminum alloy and steel welded by Fe/Al intermetaric compound that generated at weld interface. Then, the welding joints property strongly is estimated depending on the heat input and material flow during the welding.

Temperature at tool tips during the welding was measured with a thermocouple directly. The temperature was measured using a tool with built-in thermocouple. Applied forces on the weld materials during the welding were measured with a dynamometer which is set underneath the weld materials. The measured three-dimensional force is divided into horizontal components (transverse force Fx, and side force Fy) and a vertical component (down force Fz). In the experiments, internal temperature and the three-dimensional force during the welding were measured to estimate the material flow in the welding.

In addition, it was difficult to observe the material flow because metal materials were not transparent. To solve this problem, the material flow direction during the welding was investigated using a high speed video camera between transparent Poly-vinyl chloride materials as simulation experiments of aluminum alloys. Additionally, the material flow velocity was measured by the particle image velocimetry method. Also, the material flow was numerically simulated which is the finite element method and the macro-micro structure around probe was observed by stop action welding. From these analyses, material flow directions were observed different type of flow direction at advancing side and retreating side. Material flow direction at advancing side was in the reverse direction of the tool rotation that the flow phenomenon effect the defect formation in aluminum alloy was clarified.

Furthermore, the material flow during the welding of Poly-vinyl chloride and S45C as simulation experiments of aluminum alloy and steel was investigated. Also, the finite element method and macro-micro structure around probe were observed by stop action welding. From the macro structure at stop action weld, screw probe was better to effect new phase formation of steel than straight probe. Stress and strain between the butt interface and probe were concentrated.

Finally, from the results of temperature measurement at the tool tips, horizontal load, vertical load, stress and strain at the weld point and plastic flow in aluminum alloy, the formation mechanism of weld joint was clarified.