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Recycling of Machining Chips Employing Friction Stir Extrusion Process (FSEP): A Review

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Abstract

Recycling of machined chips through solid-state consolidation process, referred to as friction stir extrusion (FSEP) has been reviewed. Materials that can be consolidated are Magnesium, Aluminium Alloy and copper having excellent ductility. The method has the advantage over conventional recycling that involves melting and solidification in that, it results in energy saving, saving of time as well as reduction in greenhouse gas emissions. The properties of the products obtained through this route are reported to exhibit good mechanical properties due to freedom from solidification related defects as well as refined grain size as a result of mechanical working.

Keywords: *Machining, chips recycling, direct extrusion, Friction Stir Extrusion, Process Parameters, Microstructure, Mechanical properties*

Introduction

Lightweight materials and their alloys are employed in applications calling for weight reduction to save energy and for ease of manoeuvrability [1]. Machined chips of Al, Mg, Cu alloys can be extruded through direct conversion method consisting of powder consolidation, sintering followed by extrusion with 30-35% savings in energy, no reduction in purity, no oxidation losses due to elimination of melting and casting process and less energy consumption with zero greenhouse emissions and reduction in labour cost due to simplified waste management [2]. The direct conversion method has more advantages than the conventional method [3]. Extruded wires are free from defects and exhibited good mechanical properties due to refined grain size [4-6]. A novel and energy efficient Friction Stir Extrusion Process (FSEP) technology was introduced and developed in Oak Ridge National Laboratory (ORNL) at south wire company by W. Thomas [7-9].

This process extrudes wires from the chips by replacing powder compaction and sintering in direct extrusion. The extruded product quality depends on methods of materials to extrude into wire, process parameter such as rotational speed, axial force and chip size etc. [10-12]. Generally, there are two methods to convert the metal scrap into useful product i.e. Conventional method and Direct conversion method. In conventional method the energy consumed for extruded products is 52% only and the remaining energy is for melting, casting and dross losses in

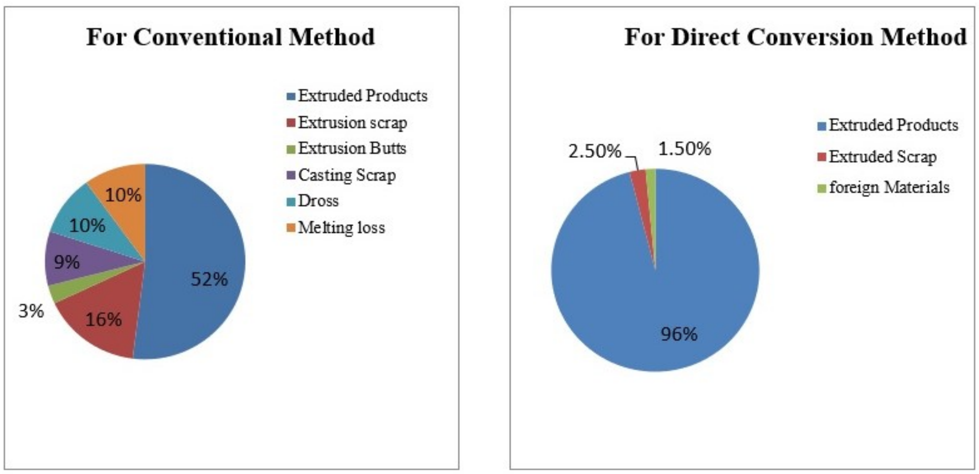

Figure.1. Comparison of energy consumption in conventional and direct extrusion processes

order to recycle into ingot form [13-16]. That results in reduction in purity of material, oxidation losses, casting defects, coarse grain size and poor mechanical properties. In addition, it requires more energy input, more labour cost. Coal and oil for melting the metal scrap results in environmental pollution [17-20]. In Direct conversion method, reduces processing time, energy consumption and produces products with good microstructure and mechanical properties. Further improvement in recycling of scrap is through a novel solid state energy efficient recycling material technology simplified by waste management with zero greenhouse gas emission developed by W. Thomas in 1993 Welding Institute of Technology England is to extrude wire or rod from machined chips directly into finished product employing Friction Stir Extrusion Process (FSEP) [21-25]. The process has significant advantages, in saving energy, reducing environmental pollution and achieves good product quality. The aim of this technique is to produce and deliver electrical cable for next generation using light weight nano materials and improve recycling efficiency up to 95% [26-30]. However, in direct conversion method, 96% of total energy is consumed for extrusion, a comparison between conventional and direct conversion methods as shown in figure.1.

In FSEP the machined chips are held in a stationary cylindrical container called cartridge and a rotating cylindrical plunger that is made to rotate in the cartridge and moves in axially downward direction under an axial pressure and a rotation, resulting in generation of heat energy due to friction to facilitate heating the metal scrap and get plasticize to consolidate.

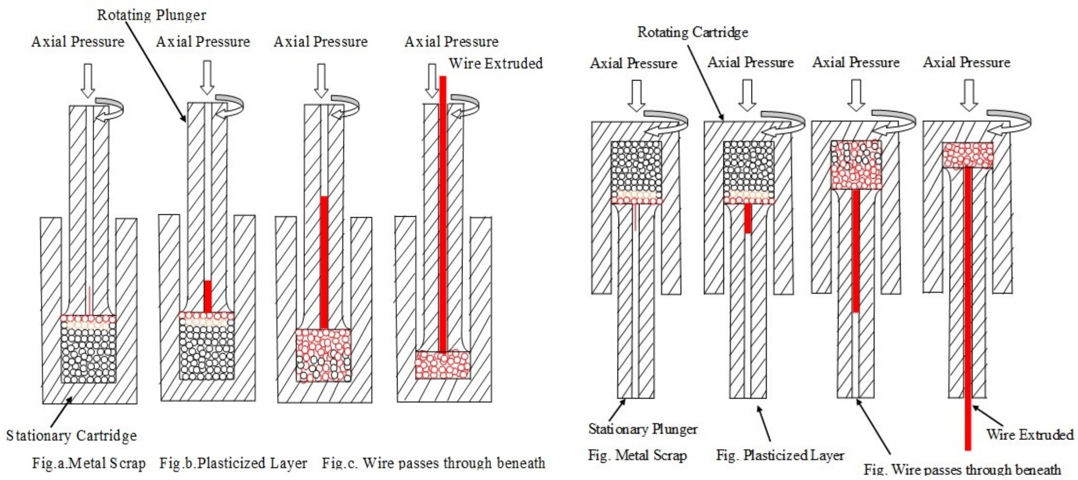

Figure. 2. Friction stir extrusion process

At this stage the metal chips are in plastic condition is made to pass through the nozzle at the bottom of the container to which a hollow cylindrical ram is attached. The material that ejects through the nozzle passes through the hollow ram beneath and takes the shape of wire. Another variation of the process is the cartridge is made to rotate keeping the plunger stationary as shown in figure.2.

Literature Review

In view of this, the observations from previous studies on Extrusion and Friction Stir Extrusion Process (FSEP) are summarised. The Magnesium Alloy AZ80, AZ31B AZ31BF, AZ91D, Aluminium Alloy AA1050, 2050, 2195, AA201, AA1050, AA6060, AA7075, AA 7277, 2025-T8, AA 6063-T52, 6061-T6, AA5052/1350, 6061/1350, 6201/1350 and Cu-Zn alloy chips were used at a speed of 90, 150,160, 160, 200, 250,355, 400, 600,700,900,1500 and 1600 rpm with an axial pressure force of 14, 18, 22kN and feed rates were 10,14, 20 and 30 mm/min 5, 7 and 9 mm in diameter of wire extruded with good quality [1-3]. The quality of wire depends on plunger rotational speed, Axial pressure force, traverse feed rate, chip quality, die design, temperatures and extrusion ratios. The common imperfections encountered were twist, cold tearing, cracks and swirl defects. High rotational speed, temperature and high strain can result in swirl defects, hot cracking, creation of voids, a sound rod and complex 3D helical material flow is generated on cross section of the extruded profile with recrystallized grains in the centre and heavily stretched grain in the periphery, while low speed and temperature resulted in cold tearing and a smooth, free from cracks, finest equiaxed grain structure could be obtained at optimum or intermediate speed. The large size chips exhibit micro-cracks and de-laminations, [4-6]. The grain size decreases from centre of wire surface whereas micro-hardness increases. The fine homogeneous microstructure showed better strength, ductility, corrosion resistance, uniform composition, free from segregation with lower friction co-efficient as compared with parent metals at optimized process parameters [7-9]. In this process an extrusion ratio was used 5, 3.57, 0.2, 0.28, 0.36, it is speculated that large extrusion ratio results in lower pressure inside the extrusion chamber, as extrusion ratio decreases quality of rod increases because of better compaction and a helical material flow found through experimental observation. In this review mechanical properties, microstructure characterization of fine and coarse grain structure was revealed [10-12]. The conventional resistive heating would be consuming more than 7000 kJ, whereas in indirect extrusion the energy consumed is mere ~207 kJ, this process also coined as Friction stir back extrusion (FSBE), it extrudes tubular profile that is structurally sound and free from the signs of voids or internal defects with Aluminium, Magnesium alloy and Copper from machined chips [13,14]. The inhomogeneous microstructure is attributed to poor deformation characteristics of Mg alloy which has HCP crystal structure [15,16]. Similar problems are not observed in aluminium alloy as it is of FCC crystal structure that has favourable number of slip systems. Extrusion marks/scratch lines were observed at the outer periphery and coarse grains were noticed along the tube wall due to trapped heat at the process parameters such as rotational speed 1500 rpm, axial force 10 kN, axial feed 0.5 mm/s, dwell time is 10s and Extrusion ratio 4.1. A significant amount of grain refinement in the microstructure, material deformation in the form of outward radial flow in the stirring zone and mechanical properties has been reported [17,18]. This technique is for high productivity with Low energy consumption, large metal savings and zero greenhouse gas emission [19-21]. As a new attempt to recycle minute metal scrap the possibility of production and design materials by semisolid process by cold pressing and hot extrusion of Aluminium, Magnesium alloy at a pressure of 240, 310 MPa, extrusion ratio is 12, 25:1 with axial feed rate of 40 mm/min, speed of 1600 rpm. The results indicate that better mechanical properties and fine-grained microstructure due to dynamic recrystallization above 400°C-500°C, at 350-400°C formation of new grains and grain refinement due to cross slip and basal slip and twinning, necklace structures are formed at 300-350°C, the dynamic recrystallization mechanisms are controlled by dislocation climb, and recrystallized grains are homogeneous [22-24]. No macro cracks or unfilled parts are visible on the surface, Moreover, there was no void defect, and an excellent inner surface was formed. In this work, Response Surface Methodology (RSM) was used to carried out experiment with three main operating variables i.e. Chip size, pre-compaction, and holding time. Holding time has the most influential effect on mechanical properties followed by pre-compaction while chip size has the least effect on UTS. It has been concluded that, hot press forging could be one of the alternative metal waste recycling processes instead of conventional method [25-27]. The numerical campaign was carried out on FSE process, aim is to investigate the process mechanics by extrusion force, velocity-controlled, extrusion rate and extrusion ratios is highly influenced by tool rotation rate applied in process simulation and directly influences the surface quality of extrudes. The temperature in the container matrix depends on heat input and process time gaining information on the material flow and better when lower rate is obtained through the combination of tool rotation and tool force [28-30]. Strain and texture in FSE Process has been carried out with extruded wires under various die rotational speed and extrusion forces such as 300, 400,500 RPM and 44.5, 80.1, 106.8 kN respectively [31]. The heat transfer phenomena in the die and plunger plays very important vital role, as the grain size increases in wire with increase of temperature, higher rotational speed results in higher temperature it leads to lower strength and better material flow [32-34]. These results are tested using the CFD simulation prediction Analytical, Numerical, Experimental and Simulation with accurate, reliable and effectively predictions have been verified [35,36]. The recycled specimens by hot-pressing and double extrusion process do not show higher ultimate tensile strength, because finer microstructures are not achieved [37-40]. The new novel solid-state technique has been developed systematically in recent years in automotive applications with the concept of light weight is predicted to be increased steadily results in homogeneous distribution of bonding interface presented, good bonding and attained excellent mechanical properties with heat treatment process [41-45]. The tensile strength, ductility and 0.2% proof stress are higher than that of the as-extruded alloys, because of precipitate strengthening, this process is optimized using the Taguchi L8 orthogonal design of experiments [46,47]. A novel severe plastic deformation (SPD), powder consolidated extrusion method has been proposed the highest pressure or pressing time that produce higher degrees of consolidation and imposes a higher amount of the plastic shear strain during the modified equal channel angular pressing (ECAP) process and compared with extrusion simulation of DEFORM 3D software [48,49]. Consolidation of the recycled scraps with increasing the extrusion ratio Ultimate tensile strength and elongation to failure increases, could produce wire with fine, an equiaxed microstructure and mechanical and tribological properties of aluminium-base composites produced by the recycling of chips [50-56]. The solid-state recycling of Mg, Al, Cu chips has become an effective and powerful methodology to investigate the theoretical model, analytical and experimental aspect of the relevant works such as cold, hot extrusion, forging, rolling, sintering, solid state recycling via ECAP etc [57-59. The basal plane texture is weakened after ECAP, the YS and UTS values of ECAPed specimens are much larger than those of extruded specimens. The grain refinement plays a more important role than texture and miscellaneous methods of FSE process by various process parameters over the quality of the extruded profiles and potential market profitability [60-63]. The damping capacity and dynamic modulus was measured as a function of time and temperature at a fixed frequency of 5 Hz and 10 to 14% increase in damping capacity [64-66]. In hot extrusion the relative densities, strength and plastic properties of the composites are almost identical as those of solid materials made from aluminium powder. An Addition of tungsten-powder and aluminium oxides, improves the strength properties, whereas addition of Carbon results in discontinuities in the structure of extruded product [67-70]. It producing bearing material of aluminium alloy and aluminium bronze chips without metallurgical process, heat treatment of copper and aluminium which leads to good tribological properties to investigate the influence of temperature and extrusion ratios on strain rate, flow stress, grain deformation, microstructure, and mechanical properties of composites [71-81]. The current technologies such as MC HPDC, BCAST, MCAST, Rheo-diecasting (RDC), Powder metallurgy, GBC, deformation mechanism, wire drawing and additive manufacturing process was used to recycle high grade Mg-alloy chips for the components of automotive applications [82-92]. In this review the environmental impacts associated with 'meltless' scrap processing with different techniques by energy saving to make materials on a global scale [93-95]. The experimental research regarding the ways of improving the quality of extruded product by various methods of extrusion process, process parameters, the influence of aging time and temperature on the microstructure and mechanical properties were investigated on the Mg, A1, Cu alloys and role of quality degradation as well as dilution losses during metal recycling [96-100].

Results And Discussions

- From the literature Machined scrap of Al, Mg, Cu alloys machined chips ware compressed by cold or hot compaction at various process parameters such as pressure, temperatures and traverse speed using conventional and direct extrusion method extruded in wire form.

- Too high temperature results in hot tear, cracks, too low temperature results in cold tear, voids whereas an intermediate speed results in defect free wire could be extruded shown in figure. The grain sizes are smaller in size at centre of wire surface whereas micro-hardness increases, it showed homogeneous microstructure, better strength, good ductility, corrosion resistance, uniform composition compared with parent metals at optimized process parameters.

- In this process large extrusion ratio results in lower pressure inside the extrusion chamber, as extrusion ratio decreases quality of rod increases because of better compaction and a helical material flow found through experimental observation.

- Friction Stir Extrusion Process is a new technique solid state recycling process with optimum cost, energy saving, eco-friendly to carried the extruded product in the form of wire 5,7 and 9 mm in diameters with smooth surface finish, good mechanical properties, microstructure characterization of fine and coarse grain structure obtained with various process parameters such as rotational speed, axial force and chip size and was compared with parent metal.

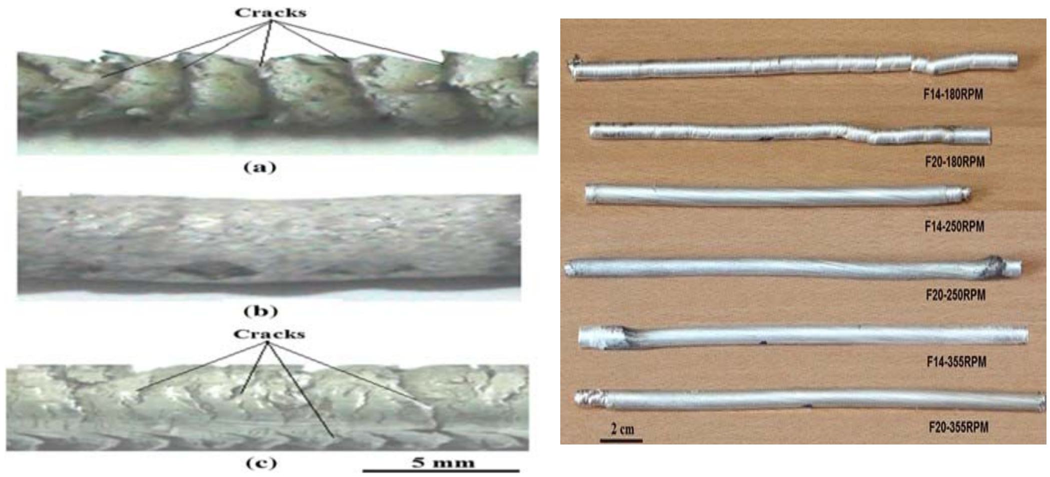

Figure.3. Wire extruded with different speeds

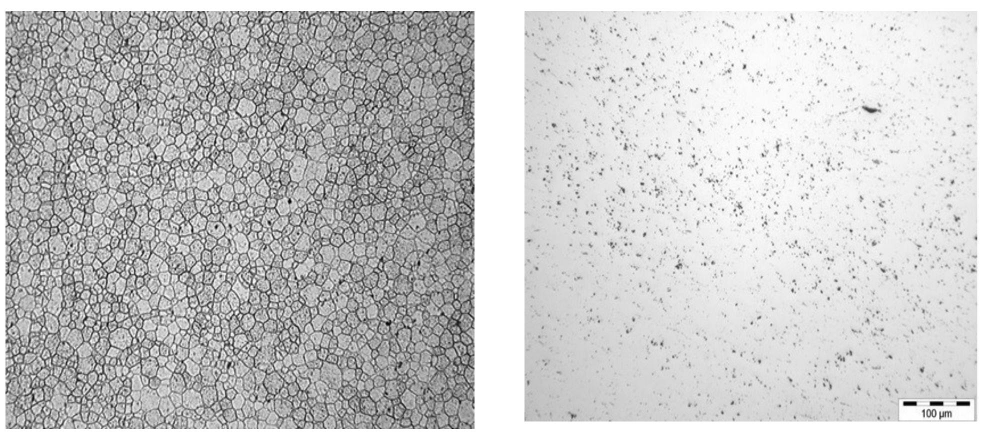

Fig. Microstructure with equi-axed grains

Conclusion

Recycling of machined chips/scrap through the conventional route, direct extrusion after cold or hot compaction and friction stir extrusion process has been reviewed. The microstructure, mechanical properties has been studies with various process parameters. The rotational speed, axial force, traverse speed, extrusion ratios, temperature and chip size play's a vital role in the quality of product obtained. High rotational speed and temperature result in hot tear and cracks, while low speed, temperature result in cold tear, whereas defect free wire could be obtained. At medium rotational speed, temperature result in uniform, equi-axed grain structure has been reported. A novel solid-state recycling meltless process coined as Friction Stir Extrusion Process is to be more promising it reduced processing time without compromising the quality of the extruded product by optimising cost, saving energy, eco-friendly, good mechanical properties.

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References

[1] Oak Ridge National Laboratory and The Welding Institute-England, “Final Technical Report”, (March 27, 2012), DE-EE003458.

[2] ABDI BEHNAGH R, MAHDAVINEJAD R, YAVARI A, ABDOLLAHI M, NARVAN M.,“Production of Wire From AA7277 Aluminum Chips via Friction-Stir Extrusion (FSE)”, J. Metall. Mater. Trans. B, 45(4) (2014), pp. 1484–1489.

[3] Masoud Abdollahi, Reza Abdi Behnagh, Javad Ghasemi, Mohammad Kazem BesharatiGivi., “Solid-state recycling of aluminium alloy chips through friction stir extrusion (FSE)”, Proceedings of Iran International Aluminum Conference (IIAC2014), May 25-26, 2014, Tehran, I.R. Iran.

[4] Reza Abdi Behnagh, Ninggang Shen, Mohammad Ali Ansari, Morteza Narvan, Mohammad Kazem Besharati Givi,Hongtao Ding., “Experimental Analysis and Microstructure Modeling of Friction Stir Extrusion of Magnesium Chips”, ASME J. Manuf. Sci. Eng., 138(2015), pp. 0410081-04100811.

[5] A. Hosseini, E.Azarsa, B.Davoodi, Y.Ardahani.,“Effect of process parameters on the physical properties of wires produced by friction extrusion method”, Int. J. Adv. Eng. Technol., 3(1)(2012), pp. 592-597.

[6] Wiewiora Marce, Wedrychowicz Mateusz, Wzorek Lukasz, “Mechanical properties of solid state recycled 6060 aluminum alloy chips”, Met., 2015, Jun 3rd - 5th 2015, Brno, Czech Republic, EU.

[7] Mohammad Sharifzzadeh, Mohammad ali Ansari, MortezaNarvan,Reza Abdi Benagh, AlirirezaAraee, Mohammad KzemBesharatigivi,“Evaluation of wear and corrosion resistance of pure Mg wire produced by friction stir extrusion (FSE)”,Trans. Nonferrous. Met. Soc., China, 25(2015), pp. 1847-1855.

[8] W.Tang, AP Reynolds., “Production of wire via friction extrusion of aluminium alloy machining chips”,J. Mater. Process. Technol., 2010, Vol. 210, pp. 2231-2237.

[9] Gianluca Buffa, Davide Campanella, Livan Fratini, Fabrizio Micari.,“AZ31 magnesium alloy recycling through friction stir extrusion process, J. Mater. Form. 2015, DOI 10.1007/s12289-015-1247-6.

[10] Dario Baffari, Gianluca, Livin Fratin, "Influence of process parameters on the product Intigrity in friction stir extrusion of magnesium alloy", J. Key. Eng. Mater, 716(2016), pp. 39-48.

[11] Dario Baffari, Gianluca Buffa, Davide Campanella, Livan Fratini, Anthony P. Renolds, "Process Mechanics in Friction Stir Extrusion of Magnesium alloy chips through Experiments and Numerical Simulation", J. Manuf. Process. 29(2017), pp. 41-49. Doi.org/10.1016/j.jmatpro.2017.07.010.

[12] Dario Baffari, Gianluca Buffa, Livan Fratini, "A numerical Model for Wire integrity Prediction in Friction Stir Extrusion of Magnesium alloys", J. Mater. Process. Tech. 247(2017), pp.1-10. Doi.org/ 10.1016/j. Jmateprotec.2017.04.007.

[13] Dario Baffari, Anthony P. Renolds, Xiao Li, Livan Fratini, "Influence of Processing Parameters and initial temper on Friction Stir Extrusion of 2050 aluminium alloy", J. Mater. Process. 28(2017), pp. 319-325. Doi.org/10.1016/j.jmapro.2017.06.013.

[14] Branimir Lela, Jure Krolo, Sonja Jozic, "Mathematical Modeling of solid-state recycling of aluminum chips", Int. J. Advan. Manuf. Technol. 2016, doi. 10.1007/s00170-016-8569-5.

[15] Fadi Abu-Farha., "Spiral Friction Stir Processing (SFSP) For the Extrusion of Lightweight Alloy Tubes", Proceedings of ASME 2012. Int. Manuf. Sci. Eng. Conf. (MSEC2012), June 4-8, 2012, Notre Dame, Indiana, USA, MSEC2012-7358, pp. 1-9.

[16] Fadi Abu-Farha.,"A preliminary study on the feasibility of friction stir back extrusion", Scripta Mater., 66(9)(2012), pp. 615-618.

[17] Fadi Abu-Farha, Justin L.Milner., "Friction Stir Back Extrusion of Mg AZ31BF: A Preliminary Investigation", The Minerals, Metals & Materials Society, 2014, pp. 497- 503.

[18] Fadi Abu-Farha, Justin L. Milner., "On The Manufacture of Lightweight Alloy Tubes via Back Extrusion: Process Evaluation and Material Performance", Proceedings of the ASME 2014 Int. Manuf. Sci. Eng. Conf., June 9-13, 2014, MSEC2014-4148, Detroit, Michigan, USA.

[19] I. Dinaharan, R.Sathishkumar, S.J.Vijay, N.Murugan., "Microstructural characterization of pure copper tubes produced by A Novel method friction stir back extrusion, Proced. Mater. Sci., 5(2014), pp. 1502-1508. doi: 10.1016/j.mspro.2014.07.337.

[20] N. Mathew, I. Dinaharan, S. J. Vijay N. Murugan., "Microstructure and Mechanical Characterization of Aluminum Seamless Tubes Produced by Friction Stir Back Extrusion",Trans Indian Inst Met, 2016, DOI 10.1007/s12666-016-0841-8

[21] Mahmoud Sarkari Khorrami, Mojtaba Movahedi., "Microstructure evolutions and mechanical properties of tubular aluminium produced by friction stir back extrusion", J. Mater. Des. 65(2015), pp. 74-79. doi.org.101016/j.matdes.2014.09018.

[22] M. Samuel., "A new technique for recycling aluminium scrap, J. Mater. Process. Technol., 135(2003), pp. 117-124. Doi: 10.1016/S0924-0136(02)01133-0.
[23] LI Dong-hua, HU Maol-iang, WANG Haibo, ZHAO Wangan., "Low temperature mechanical property of AZ91D magnesium alloy, Trans. Nonferrous Met. Soc., China, 21(2011), pp. 1234-1240. DOI: 10.1016/S10036326(11)608479.
[24] Z. Sherafat, M.H. Paydar, R. Ebrahimi., "Fabrication of Al7075/Al, two phase material, by recycling Al7075 alloy chips using powder metallurgy route ", J. Alloys Compd., 487(2009), pp. 395–399. doi:10.1016/j.jallcom.2009.07.146
[25] HU Mao-liang, JI Ze-sheng, CHEN Xiao-yu, WANG Qu-dong, DING Wen-jiang., "Solid state recycling of AZ91D magnesium alloy chips", Trans. Nonferrous. Met. Soc. China, 22(2012), pp. s68-s73.
[26] S. SUGIYAMA, T. MERA, J. YANAGIMOTO., "Recycling of minute metal scraps by semisolid processing: Manufacturing of design materials, Trans. Nonferrous. Met. Soc. China,. 20(2010), pp. 1567-1571. DOI: 10.1016/S1003-6326(09)60340-X.
[27] S.S. Khamis, M.A. Lajis, R.A.O. Albert., "A Sustainable Direct Recycling of Aluminum Chip (AA6061) in Hot Press Forging Employing Response Surface Methodology ",Proced. CIRP. 26(2015), pp. 477-481.
[28] Mohammad Ali Ansari, Mohammad Kazem Besharati Givi , Reza Abdi Behnagh, Morteza Narvan, Emadoddin Sadeqzadeh Naeini, "Solid-State production of Micro engineered advanced wire from magnesium chips by Friction Stir Extrusion, 23rd Annual Int. Conf. Mech. Engg, 12-14 May, 2015, ISME2015-10102440950.
[29] X. Li, W. Tang, A.P. Reynolds, W.A. Tayon, C.A. Brice, "Strain and Texture in Friction Extrusion of Aluminum wire, J. Mater. Process. Technol, 229 (2016), 191–198. doi.org/10.1016/j.jmatprotec.2015.09.012
[30] H. Zhang, X. Li, W. Tang, X. Deng, A.P. Reynolds, M.A. Sutton, "Heat Transfer Modeling of Friction Extrusion Process", J. Mater. Process. Technol, 221(2015), pp.21-30. Doi.org/10.1016/j.jmatprotec.2015.01.032.
[31] H. Zhang, X. Zhao, W. Tang, X. Deng, M.A. Sutton, A.P. Reynolds, S.R. McNeill, X. Ke, "Investigation of Material Flow During Friction Extrusion Process", J. Mech. sci. 85(2014), pp.130-141. Doi.org/j.ijmecsci.2014.05.011.
[32] Morteza Narvan, Reza Abdi Behnagh, Ninggang Shen, Mohammad Kazem Besharati Givi, Hongtao Ding, "Shear compaction processing of SiC nano particles reinforced magnesium composites directly from magnesium chips", J. Mauf. Process. 22(2016), PP.39-48. doi.org/10.1016/j.jmapro.2016.01.010.
[33] J.Z Gronostajski, J.W Kaczmar, H.Marciniak, A. Matuszak., "Direct recycling of aluminium chips into extruded product", J. Mater. Process. Technol, 64(1997), pp.149-156.
[34] WU Shu-yan, JI Ze-sheng, RONG Shou-fan, HU Mao-liang, "Microstructure and mechanical properties of AZ31B magnesium alloy

prepared by solid-state recycling process from Chips" , Trans. Nonferrous Met. Soc. China, 20(2010), pp. 783-788. DOI: 10.1016/S1003-6326(09)60214-4.

[35] Mostafa Akbari, Parviz Asadi, Reza Abdi Behnagh, Fevzi Bedir, Naghdali Choupani, Tomasz Sadowski, "Process Parameters and Tool Design in Friction Stir Extrusion: A Sustainable Recycling Technique", Engg Reports, 7(2025) pp. 1-39, doi.org/10.1002/eng2.13060

[36] Mao-LiangHu, Ze-ShengJi, Xiao-Yu Chen, Qu-Dong Wang, "Microstructure and mechanical properties of AZ91DMagnesium Alloy recycled from scraps by Hot press / Extrusion", J. Harbin Inst. Technol, 21(1)(2014), pp. 115-120.

[37] Mohammad Ali Ansari, Reza Abdi Behnagh, Morteza Narvan, Emadoddin Sadeqzadeh Naeini, Mohammad Kazem Besharati Givi, Hongtao Ding, "Optimization of Friction Stir Extrusion (FSE) Parameters Through Taguchi Technique", Trans Indian Inst Met.2015, DOI 10.1007/s12666-015-0686-6.

[38] Lihua Wen, Zesheng Ji, Xiaoliang Li, "Effect of extrusion ratio on microstructure and mechanical properties of Mg–Nd–Zn–Zr alloys prepared by a solid recycling process", J. Mater. Characterization 59(2008), pp.1655-1660. doi:10.1016/j.matchar.2008.03.009.

[39] HU Mao-liang, JI Ze-sheng, CHEN Xiao-yu, "Microstructure and Mechanical properties AZ31B Magnesium alloy recycled by solid state process from different chip size", J. Mater. Process. Technol. 209(2009), pp. 5319-5324. Doi:10.1016/j.jmatprotec.2009.04.002.

[40] HU Mao-liang, JI Ze-sheng, CHEN Xiao-yu, Zhenkao zhang, "Effect of chip size on and Mechanical property and Microstructure of AZ91D magnesium alloy prepared by solid state recycled", J. Mater. Characterization 59(2008), pp.385-389. doi:10.1016/j.matchar.2007.02.002.

[41] Z.S. Ji, L.H. Wen, X.L. Li, "Mechanical properties and fracture behavior of Mg–2.4Nd–0.6Zn–0.6Zr alloys fabricated by solid recycling process", J. Mater. Process. Technol, 209(2009), pp.2128-2134. doi:10.1016/j.jm atprotec.2008.05.007.

[42] Ryoichi, Tamon nakamura, Mitsutoshi kuroda, "Solid state recycling of aluminium alloy swarf through cold profile extrusion and cold rolling", J. Mater. Process. Technol, 211(2011), pp.1878-1887.doi:10.1016/j,jmatprotec.2011.06.010.

[43] LIU Ying, LI Yuan Yuan, Zhang Datong, Ngai Tung wai Leo, Chen wei ping, "Microstructure and properties of AZ80 magnesium alloy prepared by hot extrusion from recycled machined chips", Trans. Nonferrous Met. Soc. China, 129(5)(2012), pp. 882-885. Id; 1003-6326(2002)05-0882-04.

[44] Shuyan WU**,** Zesheng JI**,** Jun Wang**,** Hongbo LI**,** Shidan YUAN and Ming HU, "Microstructure and Mechanical Properties of Magnesium Alloy Prepared by Solid -state Recycling From Two Kinds of Chips", Int. Conf. Mechatronics. Robotics. Automation (ICMRA- 2015), pp. 1227-1230.

[45] Yasumasa Chino, Tetsuji, and mamoru Mabuchi, "Mechanical and corrosion properties of AZ31 Magnesium alloy repeatedly recycled by Hot Extrusion", Mater. Trans, 47(2006), pp.1040-1046.

[46] V.Guley, N.Ben Khalifa, A.E.Tekkaya, "Direct recycling of 1050 aluminum alloy scrap material mixed with 6060 aluminum alloy chips by Hot Extrusion", J. Mater Form, 3(1)(2010), pp. 853-856. Doi:10.1007/s12289-010-0904-z.

[47] J.Gronostajski, H.Marciniak, A.Matuszak, "New methods of aluminium and aluminium-alloy chips recycling", J. Mater. Process. Technol, 106(2000), pp. 34-39., PI: S0924-0136(00)00634-8.

[48] Babak Manafi, Mehdi Saeidi, "Development of novel sever plastic deformation Method: Friction stir equal channel angular pressing", Int. J. Manuf. Technol. 2016, Vol.86, pp. 1367-1374. Doi:10.1007/s00170-015-8305-6.

[49] R. Casati, X.Wei. K.Xia, D.Dellasega, A.Tuissi, E.Villa, M.Vedani, "Mechanical and functional properties of ultrafine grained Al wires reinforced by nano-AlO2 particles", Meter. Des.2014, Vol.64, pp. 102-109. Doi.org/10.1016/j.matdes.2014.07.052.

[50] N.V. Ravi Kumar, J, J Blandin, C. Desrayaud, F. Montheillet, M. Suery, "Grain refinement in AZ91 Magnesium alloy during thermomechanical Processing", mater. Eng. A. 2003, Vol.359, pp. 150-157. Doi: 10.1016/S0921-5093(03)00334-4.

[51] J.B. Fogagnolo , E.M. Ruiz-Navas, M.A. Simón, M.A. Martinez, "Recycling of aluminium alloy and aluminium matrix composite chips by pressing and hot extrusion", J. Mater. Process. Technol.143–144 (2003), pp.792–795. doi:10.1016/S0924-0136(03)00380-7

[52] H-J Hu, H Wang, Y-Y Li, M B Yang, Zhongwen, "Effective strain caused by different process conditions of extrusion-shear and its influences on the microstructure of AZ31 magnesium alloy", Indian J. Eng. Mater. Sci. 2015, Vol.22, pp.661-668.

[53] HU Mao-liang, JI Ze-sheng, CHEN Xiao-yu, "Effect of extrusion ratio on microstructure and mechanical properties of AZ91D Magnesium alloy recycled from scraps by hot extrusion", Trans. Nonferrous Met. Soc. Chaina. 20(2010), pp.987-991. DOI: 10.1016/S1003-6326(09)60246-6.

[54] Dimos Paraskevas, Kim Vanmeensel, Jef Vleugels, Wim Dewulf, Joost R. Duflou, "Solid state recycling of aluminium sheet scrap by means of spark plasma sintering", Key Eng. Mater. 2015, Vol. 639,pp 493-498. doi:10.4028/www.scientific.net/KEM.639.493.

[55] Y. Xiao, M.A. Reuter, "Recycling of distributed aluminium turning scrap", Mine. Eng. 2002, Vol.15, pp. 963-970. PI. S0892-6875(02)00137-1.

[56] W. Chmura, J. Gronostajski, "Mechanical and tribological properties of aluminium-base

[57] composites produced by the recycling of chips", J. Mater. Process Technol., 2000, Vol.106, pp. 23-27. PI: S0924-0136(00)00632-4.

[58] Shazarel Shamsudin, M A Lajis, Z W Zhong, "Solid-state recycling of light metals: A Review", Advan. Mech. Eng., 2016, Vol. 8(8), pp. 1–23, DOI: 10.1177/1687814016661921.
[59] Tatsuhiko Aizawa, Tachai luangvaranunt, Katsuyoshi Kondoh, "Solid State Recycling of Recyclable Aluminum Waste with In-process Microstructure Control", Mater. Trans., 2002, Vol. 43, pp. 315-321.
[60] M. Bakhshi- Jooybari, "A theoretical and experiental study of friction in metal forming by the use of the forward extrusion process", J. Mater. Process Technol., 2002, Vol.125-126, pp. 369-374. PI: S0924-0136(02)00343-6.
[61] J. S. Lee, Y. Chino, H. Hosokawa1, K. Shimojima, Y. Yamada, M. Mabuchi, "Deformation Characteristics at Elevated Temperature in Recycled 5083 Aluminum Alloy by Solid State Recycling", Mater. Trans., 2005, Vol. 46(12), pp. 2637-2640.
[62] W.M. Gan, M.Y. Zheng, H. Chang, X.J. Wang, X.G. Qiao ,
[63] 'K. Wu , B. Schwebke, H.-G. Brokm eier, "Microstructure and Tensile Property of the ECAPed Pure Magnesium", J. Alloys Compounds, 2009, Vol. 470, pp. 256–262. doi:10.1016/j.jallcom .2008.02.030
[64] Mamoru Mabuchi, Kohei Kubota, Kenji Higashi, "New Recycling Process by Extrusion for Machined Chips of AZ91 Magnesium and Mechanical properties of Extruded bars", Mater. Trans. JIM, 1995, Vol.36, pp. 1249-1254.
[65] Yasumas Chino, Lee Jae-Seol, Ysuke Nakaura, koichi Ohori, mamoru Mabuchi, "Mechanical Properties of Mg-Al-Ca Alloy Recycled by Solid state recycling", Mater. Trans., 2005, Vol. 46(12), pp. 2592-2595.
[66] S Shamsudin, Z.W. Zhong, S.N Ab Rahim, M.A. Lajis, "The influence of temperature and preheating time in extruded quality of solid-state recycled aluminium", Int. J. Adv. Manuf. Technol. Doi: 10.1007/s007-016-9521-4.
[67] YING Tao, ZHENG Ming-yi, HU Xiao-shi, WU Kun, "Recycling of AZ91 Mg alloy through consolidation of machined chips by extrusion and ECAP", Trans. Nonferrous. Met. Soc. China., 2010, Vol. 20, s604-s607.
[68] Adam J. Gesing, Subodh K. Das, Raouf O. Loutfy, "Production of Magnesium and Aluminium-Magnesium Alloys from Secondary Aluminium Scrap melts", The Minerals, Met & Meter. Soc.2016, Vol. 68(2), pp. 581-592. Doi: 10.1007/s11837-015-1720-1.
[69] Yasumasa Chino, Tetsuji Hoshika, Mamoru Mabuchi, "Enhanced Corrosion Properties of Pure Mg and AZ31 Mg Alloy Recycled by Solid-State Process", Mater. Sci. Engg. A 2006, Vol. 435-436, pp. 275-281. Doi: 10.1016/j,msea.2006.07.019.
[70] A.R. Anilchandra, M.K. Surappa, "Microstructure and damping behavior of consolidated Magnesium chips", Mater. Sci. Eng. A. 2012, Vol. 542, pp.94-103. Doi: 10.1016/j,msea.2012.02.038.
[71] Ryoichi Chiba, Morihiro Yoshimura, "Solid-state recycling of aluminium alloy swarf into C- channel by hot extrusion", J. Manuf. Process. 2015, Vol. 17, pp. 01-08, doi.org/10.1016/j.jmapro.2014.10.002.

[72] J. Gronostajski, A. Matuszak, “The recycling of metals by plastic deformation: an example of recycling of aluminium and its alloys chips”, J. Mater Process. Technology, 1999, Vol. 92-93, pp. 35-41. PI: S0924 - 0136(99)00166-1.

[73] J. Gronostajski, W. Chmura, Z. Gronostajski, Bearing materials obtained by recycling of aluminium and aluminum bronze chips”, J. Mater Process. Technology, 2002, Vol. 125-126, pp. 483-490. PI: S0924-0136(02)00326-6.

[74] Matthias Haase, A. Erman Tekkaya, “Cold extrusion of hot extruded aluminum chips”, J. Mater Process. Technology, 2015, Vol. 217, pp. 356-367. doi.org/10.1016/j.jmatprotec.2014.11.028.

[75] G. Hanko, H. Antrekowitsch, P. Ebner, “Recycling Automotive Magnesium Scrap”, JOM. 2002, pp. 51-54.

[76] S. Tzamtzis, H. Zhang, M. Xia, N. Hari Babu, Z. Fan, “Recycling of high grade die casting AM series magnesium scrap with the melt consolidated high pressure die casting (MC-HPDC) process”, Mater. Sci. Eng. A. 2011, Vol. 528, pp. 2664-2669. Doi:10.1016/j.msea.2010.12.001.

[77] G. Liu, Y. Wang, Z. Fan, “A physical approach to the direct recycling of Mg-alloy scrap by the rheo-diecasting process”, Mater. Sci. Eng. A. 2008, Vol. 472, pp. 251-257. Doi:10.1016/j.msea.2007.03.026.

[78] Mohd Warikh ABD RASHID, Fariza Fuziana YACOB, Mohd Amri LAJIS, Mohd Asyadi’ Azam MOHD ABID, Effendi MOHAMAD, Teruaki ITO, “A Review: The Potential of Powder Metallurgy in Recycling Aluminum Chips (Al 6061 & Al 7075)”, DOI: 10.13140/2.1.2402.6887.

[79] Jirang CUI, Hans J. ROVEN, “Recycling of automotive aluminum”, Trans. Nonferrous. Met. Soc. China., 2010, Vol.20, pp.2057-2063. DOI: 10.1016/S1003-6326(09)60417-9.

[80] W. Chmura, Z. Gronostajski, “Bearing composites made from aluminium and aluminium bronze chips”, J. Mater. Process. Technol., 2006, Vol. 178, pp.188-193. doi:10.1016/j.jmatprotec.2006.03.156.

[81] Hakaru Nakato, Michio Oka, Seiji Itoyama, Masao Urata, Tatsuo Kawasaki, Ko-ichi Hashiguchi, Shinobu Okano, “Continuous Semi-Solid Casting Process for Aluminum Alloy Billets”, Mater. Trans., 2002, Vol. 43(1), pp.24-29.

[82] Y. Uematsu, K. Tokaji, M. Kamakura, K. Uchida, H. Shibata, N. Bekku, “Effect of extrusion conditions on grain refinement and fatigue behaviour in magnesium alloys”, Mater. Sci. Eng. A., 2006, Vol. 434, pp.131-140. Doi:10.1016/j.msea.2006.06.117.

[83] G. Gaeces, F. Dominguez, P. Perez, G. Caruana, P. Adeva, “Effect of extrusion temperature on microstructure and plastic deformation of PM-AZ92”, J. All. Comp., 2006, vol.422, pp.293-298. Doi:10.1016/j.jallcom.2005.11.069.

[84] Hidetoshi Somekawa, Toshiji mukai, “Effect of grain refinement on fracture toughness in extruded pure magnesium” Scripta mater. 2005, Vol.53, pp.1059-1064. Doi:10.1016/j.scriptamat.2005.07.001.

[85] Tomotake Hirata, Toshihiro Osa, Hiroyuki Hosokawa, Kenji Higashi, "Effects of Flow Stress and Grain Size on the Evolution of Grain Boundary Microstructure in Superplastic 5083 Aluminum Alloy", Mater. Trans., 2002, Vol. 43(10), pp.2385-2391.

[86] Muhammad Shahzad, Lothar Wagner, "Influence of extrusion parameters on microstructure and texture developments, and their effects on mechanical prosperities of the magnesium alloy AZ80", Mater. Sci. Eng. A. 2009, Vol.506, pp. 141-147. doi:10.1016/j.msea.200811.038.

[87] Jian-Yih Wang, Ying-Nan Lin, Tien-Chan Chang, Shyong Lee, "Recycling the Magnesium Alloy AZ91D in Solid State", Mater. Trans., 2006, Vol. 47(4), pp. 1047-1051.

[88] Li Wen-Juan, Zhao Guo-Qun, Ma Xin-Wu, and Gao Jun, "Flow Stress Characteristics of AZ31B Magnesium Alloy Sheet at Elevated Temperature", Int. J. Appl. Phys. Math. 2012, Vol. 2(2), pp.1-6.

[89] Gow-Yi Tzou, Dyi-Cheng Chen, Shih-Hsien Lin, "Study on wire Rod Drawing Process using Rotating Die", Key. Eng. Mater., 2016, Vol.716, pp.63-67. Doi; 10.402/www.scientific.net/KEM.716.63.

[90] Mohammad ASGARI, Faram arz FERESHTEH-SANIEE, "Production of AZ80 /Al composite rods employing non-equal channel lateral extrusion", Trans. Nonferrous Met. Soc. China., 2016, Vol.26, pp.1276−1283. DOI: 10.1016/S1003-6326(16)64228-0.

[91] Andrij Milenin, Piotr Kustra, Dorota Byrska-Wojcik, Bartlomiej Plonka, Veronika petranova, Vladimir Hebek, Jiri Nemecek, "Numerical Optimization and practical Implementation of tube Extrusion Process of Mg Alloys with Micromechanical Analysis of the Final Product", Key. Eng. Mater., 2016, Vol.716, pp.55-62. Doi:10.4028/www.scientific.net/KEM.716.55.

[92] A. Azushima, R. Kopp, A. Korhonen, D.Y. Yang, F. Micari, G.D. Lahoti, P. Groche, J. Yanagimoto, N. Tsuji , A. Rosochowski , A. Yanagida, "Severe plastic deformation (SPD) processes for metals", CIRP Annals – Manuf. Technol.,2008, Vol. 57, pp.716-735. doi:10.1016/j.cirp.2008.09.005.

[93] Tae-hyuk LEE, Moon-soo SIM, Sin-hyeong JOO, K young-tae PARK, Ha-guk JEONG, Jong-hyeon LEE, "Effect of intermetallic compound thickness on anisotropy of Al/Cu honeycomb rods fabricated by hydrostatic extrusion process", Trans. Nonferrous Met. Soc. China., 2016, Vol. 26, pp.456-463. DOI: 10.1016/S1003-6326(16)64134-1.

[94] Z.Y. Ma, R.S. Mishra, M.W. Mahoney, R. Grimes, "High strain rate super plasticity in friction stir processed Al-Mg-Zr alloy", Mater. Sci. Eng. A., 2003, Vol.351, pp.148-153. PI: S0921-5096(02)00824-9.

[95] Timothy G. Gutowski, Sahil Sahni, Julian M. Allwood, Michael F. Ashby, Ernst Worrell, "The energy required to produce materials: constraints on energy-integrity improvements, parameters of demand", rsta.royalsocietypublishing.org/ on January 14, 2015, doi.org/10.1098/rsta.2012.0003.

[96] DING Xian-fie, SUN Jing, YING Jia, ZHANG Wei-dong, MA Ji-jun, WANG Li-chen, "Influence of aging temperature and time on microstructure and mechanical properties of 6005A aluminum alloy extrusion", Trans. Nonferrous meter. Soc. China 2012, Vol.22, pp.s14-s20.
[97] Teodor Socaciu, "Experimental study regarding variation of force in inverse extrusion using active friction", Procedia Technol., 2015, Vol.19, pp.85-89.
[98] Ryo Matsumoto, Kazunori Hayashi, Hiroshi Utsunomiya, "Experimental and numerical analysis of friction in high aspect ratio combined forward-backward extrusion with retreat and advance pulse ram motion on a servo press", J. Mater. Process. Technol., 2014, Vol. 214, pp.936-944. doi.org/10.1016/j.jmatprotec.2013.11.017.
[99] Gaojin Chen, Liang Chen, Guoqun Zhao, Cunsheng, Zhang, Weichao Cui, "Microstructure analysis of an Al-Zn-Mg alloy during parthole die extrusion based on modeling of constitutive equation and dynamic recrystallization", J. All. Com, 2017, Vol. 710, pp. 80-91. Doi.org/10.1016/j.jallcom.2017.03.240.
[100] Dimos Paraskevas, Karel kellen, Wim Dewulf, Joost R. Duflou, "Environmental modeling of aluminium recycling: a life cycle assessment tool for sustainable metal management", J. Clean. Prod., 2014, pp. 01-14. doi.org/10.1016/j.jclepro.2014.09.102.
[101] V.Jayaseelan, K. Kalaichelvan, "Influence of Friction Factor on Extrusion process", Advan. Mater. Res., vol. 622-623, 2013, pp.457-460. Doi: 10.4028/www.scientific. net/AMR.622-623.457.
[102] Joost R. Duflou, A. Erman Tekkaya, Matthias Haase, Torgeir Welo, Kim Vanmeensel, Karel Kellens, Wim Dewulf, Dimos Paraskevas, "Environmental assessment of solid-state recycling routes for aluminum alloy: Can solid state processes significantly reduce the environmental impact of aluminium recycling?", 2015, doi.org/10.1016/j.cirp.2015.04.051.