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Mini Review

Methods to Re-Use and Recycle Aluminium Machining Swarf

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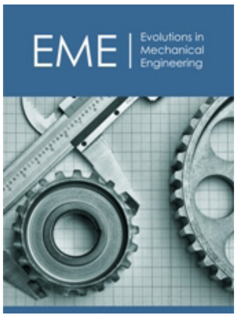

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Abstract

Large amounts of aluminium end up as machining swarf disposed of in landfills, reducing the amount of aluminium used for the actual manufacturing, and increasing the cost of the final product, thus ultimately contributing to environmental pollution. Finding a way to remove the aluminium oxide layer that is formed in the surface of the swarf, is the main challenge faced during the recycling process of this material. This paper aims at presenting a short review of the challenges and the methods employed for swarf recycling.

Keywords: Re-use; Recycle; Aluminium; Swarf; Oxide layers

Introduction

Aluminium swarf is a waste by-product obtained through the machining of aluminium billets, ingots and castings, when components are manufactured. This waste product has a large surface area to volume ratio, making it. readily oxidised and it is very often mixed with lubricants and cutting fluids used in prior processes. In some cases, this can also include debris from the cutting tools, contaminating the waste stream making it increasingly difficult to recycle. More than 40,000 tons of swarf is generated every year by only one of the three major auto producers [1]. With disposal costs as high as $150 per ton, the amount of material is seen as a major cost to the industry [1]. This costly scrap is an untapped source of raw material, which to date finds very limited use.

The UK government [2] in its annual report states that 54% of aluminium waste until now is recycled and sustainable business sources [3] urge the British government to ensure that nearly 100% of aluminium should be recycled, which in return should save £50 million in material and energy, and cut 2Mt CO_2 emissions profitably and without significant capital investment [4].

To date aluminium swarf is generally disposed of by the manufacturing companies and with the increase demand for aluminium which expected to be to 60% in 2020 [5] swarf disposed it is expected to increase. This process has been facilitated with the commercialization of briquette compacting machines by companies, such as Lubriserv [6] and Ruf, each of whom sold more than 4,500 machines in the last 20 years. There is no published data to indicate the number of companies that have swapped free loose swarf for compacted swarf; however, the conditions such as ease in handling and transportation, using small amount of cooling lubricants and fast clean and clear area during machining, indicate that it is more efficient for companies to buy a continuous swarf compacting machine [6,7].

Consequently, large recyclers add a limited number of briquettes (up to 5% of the charge) [8] to large melts, thereby partially recycling them, whilst also taking care to avoid altering the overall composition of the melt through contamination. However, more can be done to increase the amount of recycled swarf, possibly even commending in-house methods developed by the manufacturers, to directly regain raw material lost during component production. The main challenges [9-11] identified during recycling which needs addressing in order to increase the amount of recycled aluminium swarf are:

A. A large amount of material loss as dross during melting, due to the significant surface area that is oxidised in contact with air;

B. The aluminium oxide layer which hinders wetting preventing bonding between pure metal grains, hence oxide films remain entrapped in the aluminium; and

C. The very low density of swarf that is added to the melt does not allow complete mixing. However, solid state methods [12-22], which would avoid the high losses of metal through dross, are particularly difficult to upscale because of: (i) the large pressure they need for small amount of material; (ii) a continuous process is difficult to achieve; (iii) the control of the defects that might occur due to inconsistent or contaminated feedstock during machining is complex; and, (iv)some extrusion methods require the repetition of several cycles in order to obtain a recycled material within specification.

Aluminium Oxide layer

In contact with air, aluminium forms a very hard aluminium oxide passivation layer, which prevents any other changes in the bulk aluminium occurring [23]. The oxide layer is normally around 10 nanometres [24]. The oxide layer forms on the swarf as soon as it is produced, exacerbated by their high area/volume ratio, thus increasing the difficulties for their recyclability. Hence, a detailed understanding of the characteristics of the oxides in the swarf is essential to improve the recyclability of this material.

Different sizes and shapes of chips affect the amount of oxides in the swarf. Small chips introduce more oxides in the material that would be recycled [13,25]. Another factor is the high temperature experienced during their creation which could come as result of the swarf's heat treatment process [26], the machining process [27] and the intense local heating during extrusion [17,28].

When recycling aluminium swarf, the aluminium oxide layer creates a considerable problem, limiting the bonding of aluminium metal between adjacent swarfs. Various researchers [9,27,29,30] have reported that if the aluminium oxide layer is broken and dispersed in the matrix, then the recycled material displays an increased yield strength, tensile strength and microhardness, as a composite made of aluminium and alumina particulate is formed. However, they also observed that the plastic properties of this recycled aluminium composite decreased significantly. However, other authors [18], observed that oxides stimulate cavity nucleation, thus generating premature fractures which reduces the elongation of the material as the oxide content increases. Moreover, they noted that the concentration of oxides has minor effects on the mechanical properties of the recycled materials [13,31], in contradiction with what previously presented. Overall, in terms of bonding between the swarf flakes, the oxide layer is always seen as a barrier, both the liquid and solid methods for recycling swarf.

Manufacturing Methods

Chemical, liquid and solid state (extrusion) methods are the 3 main methods used to treat swarf to bring them in suitable conditions to be recycled into other materials such as aluminium powders, foams, cast billets and extrudates. The treatment process is different in each of these methods and it is explained below.

Chemical methods

Chemical methods consist of treating the machining swarf with chemicals, such as sodium hydroxide or hydrochloric acid. During this treatment, the aluminium oxide layer reacts with the acid/hydroxide and thus exposes the pure aluminium. which then oxidises, however this fresh oxide layer is uniform making swarf suitable for powder production. The aluminium swarf is then used to produce loose powder, which can be used in fingerprinting, in the die industry [32,33], or pre-compacted powder [34]. In addition to powder metallurgy, these powders could be also used to produce foams [26,35].

Liquid methods

Since the early stages of machining products from metals, swarf was produced. To help its recovery, they were introduced into melts of virgin metal, in order to form cast billets. However, few issues were observed. The material had very low density, hence floating on the melt, which reduced its recovery rate significantly to ~45-50%. Researchers [36,37] have tried to find solutions to this, e.g. by building ad hoc melting furnaces which reduce the contact between the swarf with the atmosphere, allowing the ingress of the material from the deepest part of the furnace [37]. Alternatively, an induction furnace was used to improve melt circulation in a protective atmosphere to minimise further oxidation [38]. However, an extra processing step was required before melting, which involved extruding the swarf to increase the density and prevent floating [19].

Solid state

Extrusion uses severe plastic deformation to break the oxide layer and expose fresh aluminium. This fresh aluminium of adjacent swarf bonds with each other forming high density compacts [39,40]. In order to get a very compact and high density billet it is important to increase the plastic deformation during processing, which could be done by using a porthole die, complex geometries die, ECAP with porthole die, using friction back stir extrusion [14,18,41-45]. Another way to facilitate the extrusion process it to add a reinforcing material which produces a good diffusion bond between phases while both phases are similar size [46].

These methods even though used suitable strategies to recycle swarf due to challenges mentioned above are not used industrially, where the only used method is the use of small volumes of swarf in large melts in large recycler facilities. New methods easily up scalable, with modular capabilities for the on-site compacting systems could be a game-changing technology to minimize the problem of swarf overflow.

Summary

It is vital for the sustainability of aluminium sourcing and the manufacturing economy to make use of the large amount of swarf produced during machining processes. It is the aluminium oxide layer that is the main barrier that prevents the recycling of this waste stream. Engineering manufacturing research has attempted to overcome this problem by trying to remove it (as dross) in the liquid state; or clean it prior to re-use in the chemical methods; or break it using large shear deformation in solid-state methods; or insert a new reinforcing material that would improve bonding between adjacent swarf in composite manufacturing methods. There is an urgent need for increasing the amount of recycled materials, however all the recycling methods currently employed face serious challenges.

References

1. Hess MJ, Kawatra SK (1999) Environmental beneficiation of machining wastes-Part I: Material characterization of machining swarf. Journal of the Air & Waste Management Association 49(2): 207-212
2. Service GS (2019) UK statistics on waste. In: Affairs DfEFR (edn), p. 20.
3. Green B (2019) Government urges to go “all in” and ensure nearly 100% of aluminium is recycled.
4. Julian AM, Jonathan CM, Daniel CR, Rachel ML, Alexandra PCH, et al. (2010) Conserving our metal energy: Avoiding melting steel and aluminium scrap to save energy and carbon. Department of Engineering, Low Carbon and Materials Processing, University of Cambridge, UK.
5. Shahrom MS, Yusoff AR (2014) Review of aluminum chip machining using direct recycling process. Advanced Materials Research 903: 157-162.
6. Lubriserv (2019) Swarf processing lubriserv metalworking fluids and equipment.
7. System RB (2019) Ruf Briquetting System Ruf, pp Ruf Is North America’s premier briquette machine manufacturer.
8. Ruf briquetting melting adding value.
9. Gronostajski JZ, Marciniak H, Matuszak A (1996) Production of composites on the base of AlCu4 alloy chips. Journal of Materials Processing Technology 60(1-4): 719-722.
10. Gronostajski JZ, Kaczmar JW, Marciniak H, Matuszak A (1997) Direct recycling of aluminium chips into extruded products. Journal of Materials Processing Technology 64(1-3): 149-156.
11. Shamsudin S, Lajis MA, Zhong ZW (2016) Evolutionary in solid state recycling techniques of aluminium: A review. 13th Global Conference on Sustainable Manufacturing-Decoupling Growth from Resource Use 40(2016): 256-261.
12. Aizawa T, Luangvaranunt T, Kondoh K (2002) Solid state recycling of recyclable aluminum wastes with in-process microstructure control. Materials Transactions 43(3): 315-321.
13. Chino Y, Mabuchi M, Iwasaki H, Yamamoto A, Tsubakino H (2004) Tensile properties and blow forming of 5083 aluminum alloy recycled by solid-state recycling. Materials Transactions 45(8): 2509-2515
14. Chiba R, Nakamura T, Kuroda M (2011) Solid-state recycling of aluminium alloy swarf through cold profile extrusion and cold rolling. Journal of Materials Processing Tech 211(11): 1878-1887.
15. Gueley V, Guezel A, Jaeger A, Ben Khalifa N, Tekkaya AE, et al. (2013) Effect of die design on the welding quality during solid state recycling of AA6060 chips by hot extrusion. Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing 574: 163-175.
16. Badarulzaman NA, Karim SR, Lajis MA (2014) Fabrication of Al-Sn composites from direct recycling aluminium alloy 6061. 4th Mechanical and Manufacturing Engineering 465-466(1-2): 1003-1007.
17. Cooper DR, Allwood JM (2014) The influence of deformation conditions in solid-state aluminium welding processes on the resulting weld strength. Journal of Materials Processing Tech 214(11): 2576-2592.
18. Chiba R, Yoshimura M (2015) Solid-state recycling of aluminium alloy swarf into c-channel by hot extrusion. Journal of Manufacturing Processes 17: 1-8.
19. Paraskevas D, Vanmeensel K, Vleugels J, Dewulf W, Joost R Duflou (2015) Solid state recycling of aluminium sheet scrap by means of spark plasma sintering. Key Engineering Materials 639: 493-498.
20. Li X, Tang W, Reynolds AP, Tayon WA, Brice CA (2016) Strain and texture in friction extrusion of aluminum wire. Journal of Materials Processing Technology 229: 191-198.
21. Shamsudin S, Lajis MA, Zhong ZW (2016) Solid-state recycling of light metals: A review. Advances in Mechanical Engineering 8(8).
22. Li X, Baffari D, Reynolds AP (2018) Friction stir consolidation of aluminum machining chips. The International Journal of Advanced Manufacturing Technology 94: 2031-2042.
23. Davis JR (2001) Aluminium and aluminium alloys. ASM International, p. 784.
24. Alexander MR, Thompson GE, Zhou X, Beamson G, Fairley N (2002) Quantification of oxide film thickness at the surface of aluminium using XPS. Surface and Interface Analysis 34(1): 485-489.
25. Tekkaya AE, Schikorra M, Becker D, Biermann D, Hammer N, et al. (2009) Hot profile extrusion of AA-6060 aluminum chips. Journal of Materials Processing Technology 209(7): 3343-3350.
26. Kumar GSV, Heim K, Garcia-Moreno F, Banhart J, Kennedy AR (2013) Foaming of aluminum alloys derived from scrap. Advanced Engineering Materials 15(3): 129-133.
27. Samoshina M, Aksenov A, Kaevitser E (2008) Structure and properties of mechanically alloyed composite materials from hard-recycling scrap of Al alloys. Reviews on Advanced Materials Science 18: 305-310.
28. Cooper DR, Song J and Gerard R (2018) Metal recovery during melting of extruded machining chips. J Clean Prod 200: 282-292.
29. Gronostajski JZ, Kaczmar JW, Marciniak H, Matuszak A (1998) Production of composites from Al and AlMg2 alloy chips. Journal of Materials Processing Technology 77(1-3): 37-41.
30. Dimos Paraskevas, Vanmeensel K, Vleugels J, Dewulf W, Duflou JR (2015) Solid state recycling of aluminium sheet scrap by means of spark plasma sintering. Key Engineering Materials 639: 493-498.
31. Chino Y, Lee JS, Nakaura Y, Ohori K, Mabuchi M (2005) Mechanical properties of Mg-Al-Ca alloy recycled by solid-state recycling. Materials Transactions 46(12): 2592-2595.
32. Hong SH, Lee DW, Kim BK (2000) Manufacturing of aluminum flake powder from foil scrap by dry ball milling process. Journal of Materials Processing Tech 100(1-3): 105-109.
33. Hong SH, Kim BK (2001) Fabrication of aluminum flake powder from foil scrap by a wet ball milling process. Materials Letters 51(2): 139-143.
34. Samuel M (2003) A new technique for recycling aluminium scrap. Journal of Materials Processing Tech 135(1): 117-124.
35. Moloodi A, Raiszadeh R (2011) Fabricating Al foam from turning scraps. Materials and Manufacturing Processes 26(7): 890-896.
36. Shoji T, Masaaki T (1995) Aluminum swarf melting device.

37. Takebe S (1983) A furnace for melting metal swarf.
38. Puga H, Barbosa J, Soares D, Silva F, Ribeiro S (2009) Recycling of aluminium swarf by direct incorporation in aluminium melts. Journal of Materials Processing Tech 209(11): 5195-5203.
39. Chmura W, Gronostajski Z (2006) Bearing composites made from aluminium and aluminium bronze chips. Journal of Materials Processing Technology 178(1-3): 188-193.
40. Chmura W, Gronostajski Z (2007) Bearing materials obtained by diffusion bonding of aluminium and aluminium bronze chips. Archives of Civil and Mechanical Engineering 7(2): 53-66.
41. Guley V, Ben Khalifa N, Tekkaya AE (2011) The effect of extrusion ratio and material flow on the mechanical properties of aluminum profiles solid state recycled from 6060 aluminum alloy chips. 14th International Conference on Material Forming Esaform (AIP Conference Proceedings), Queens University, Belfast, North Ireland, UK, pp. 1609-1614.
42. Guley V, Guzel A, Jager A, Ben Khalifa N, Tekkaya AE (2013) Effect of die design on the welding quality during solid state recycling of AA6060 chips by hot extrusion. Materials Science and Engineering Structural Materials Properties Microstructure and Processing 574: 163-175.
43. Haase M, Ben Khalifa N, Tekkaya AE, Misiolek WZ (2012) Improving mechanical properties of chip-based aluminum extrudates by integrated extrusion and equal channel angular pressing (iECAP). Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing 539: 194-204.
44. Misiolek WZ, Haase M, Ben Khalifa N, Tekkaya AE, Kleiner M (2012) High quality extrudates from aluminum chips by new billet compaction and deformation routes. CIRP Annals 61(1): 239-242.
45. Mehtedi El M, Forcellese A, Mancia T, Simoncini M, Spigarelli S (2019) A new sustainable direct solid state recycling of AA1090 aluminum alloy chips by means of friction stir back extrusion process. 12th CIRP Conference on Intelligent Computation in Manufacturing Engineering 79: 638-643.
46. Chmura W, Gronostajski J (2000) Mechanical and tribological properties of aluminium-base composites produced by the recycling of chips. Journal of Materials Processing Technology 106(1-3): 23-27.