Editorial

Problems in the Welding of Automotive Alloys

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Many thousands of research papers have been published on automotive materials over the past five years, focusing primarily on steel, aluminium and magnesium based alloys. Much of the work has not led to commercial applications because, as stated by Miracle,[1] 'there is much work between measuring a single attractive property in a single alloy to demonstrating credibility for a particular application'. The studies published are often incomplete and it is common to ignore the fact that welding is an essential component of automobile manufacture.[2] It would not, therefore, make sense to embark on research to create a new automotive sheet material without laying out a strategy for joining that ensures the structural integrity of the car during service. It is not surprising that the highly successful dual phase steels[3] can be welded using resistance spot welding, laser welding and arc welding,[4] and possibly, using friction stir spot welding,[5] although in the latter case, there would need to be a clear technological need since the other methods are well-established and reliable. In contrast, TRIP-assisted steels[6,7] although commercialised, have been less successful due to their relatively poor weldability. This is because TRIP-assisted steels have a large carbon equivalent so that the heat-affected zones of resistance spot welds can reach hardness levels as large as 500 HV.[8] Coated twinning-induced plasticity steels also are problematic to weld due to liquation cracking[9–13] and welds in uncoated TWIP steels can lead to a localised depletion of manganese because of its high vapour pressure.[14]

In the case of magnesium alloys, techniques such as resistance spot welding or laser welding are inadequate due to the formation of voids and cracks.[15,16] This conclusion is not universally accepted. For example, Robson[17] claims that similar magnesium alloy welds can be made using a wide range of both fusion and solid-state processes.

Whereas automobiles can essentially be constructed using steels, it is unlikely they can ever be manufactured using just aluminium or magnesium alloys. It therefore becomes essential to develop joining techniques for dissimilar metals,[18,19] and even between different classes of alloy systems.[20–23] Magnesium in many automotive applications requires to be joined to aluminium, and there are important problems with the formation of brittle intermetallic compounds at the junctions.[24]

There clearly are joining related issues that need to be the focus of research before claiming success in the development of materials for automotive applications. This was the motivation for the creation of this thematic issue of the journal; although the topics covered are not comprehensive, the contributions that made it through the refereeing system are fascinating. Some of the work on joining needs to be of a fundamental nature in order to inspire breakthroughs. The study by Lin and co-workers[25] addresses the wetting of Zn-coated steel by aluminium to understand the structures that develop in the zinc-rich zone at the junction with aluminium. The results, which emphasise the importance of reaction rather than wettability, may be useful in optimising the joining of steel to aluminium alloys. An innovative solution to the joining of very strong aluminium alloys involves post-weld friction stir processing used to modify the surface structure and improve the stress corrosion resistance without greatly compromising the strength.[26] The authors admit that this may not be a practical solution in a mass production scenario where any additional steps introduce cost and complexity.

The paper by Wakabayashi and Miyazaki[27] uses a basic and well-established fact that martensite that forms at a high temperature will autotemper and hence soften. So, how can the martensite-start temperature be raised without changing the steel composition? They increase the heat input of welding, which leads to an increased austenite grain size, and a substantial rise in the martensite-start temperature. This results in a mechanically superior joint. The role of austenite grain size is well-established[28] but its application to resistance spot welding is ingenious.

There are two articles on heavy vehicles (e.g. 9000 kg weight). The first[29] has the aim of reporting new discoveries that aim to show how welding can achieve weight savings in trucks. Heat treatments to improve the fatigue life of highly-stressed components, and avoiding distortion due to welding feature high in the slimming of large vehicles. The second paper[30] deals with gigantic equipment of the type used in the oil sands mines at Alberta. Naturally, fatigue resistance of welded joints is of prime concern, but so is wear resistance. Given the punishment that such equipment must go through during service, there is also a unique requirement that there must exist rapid methods of implementing repair. Both of these papers make fascinating reading, covering subjects that for some reason are not prominently covered in the research literature.

There is a yearning in industry to make dual phase steels that are stronger while, as usual in such demands, maintaining all other properties. However, to join a 1000 MPa dual phase steel that is coated is no easy task. Wei and coworkers[31] claim partial success using a fibre laser to make lap joints. By adjusting

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conditions to produce a keyhole during laser welding, they claim that an escape route is provided for zinc vapourised at the faying surfaces. On the theme of dual phase steels, an interesting attempt is reported at joining a magnesium alloy to a (coated) conventional dual phase steel.[32] Unusually, the formation of $FeAl_2$ at the junction with magnesium helps the integrity of the joint by forming a transition layer between the magnesium and steel; the aluminium is said to originate from the galvanised layer.

One of the most active research groups on automotive welding is that of Pouranvari, who wrote an excellent critical assessment of automotive steel welding in 2013.[33] The group's contribution to this thematic issue concerns the resistance spot-welding of stainless steel where phase transformations can influence not just the mechanical properties, but often more importantly, the corrosion behaviour. Some significant conclusions are reached in the second part of the study,[34] that there is dramatic softening in the heat-affected zone of the austenitic stainless steel, but not so with the ferritic stainless where phase changes contribute to the variation in hardness.

Techniques such as ultrasonic welding are proposed for the welding of battery components in electric vehicles; a numerical study of the process, with experimental validation,[35] indicates that heat generation from friction and induced plasticity both contribute significantly to the heat input.

We hope that this special issue of the journal stimulates further innovations and look forward to exciting submissions. We thank all the authors who contributed on time.

References

1. D. B. Miracle: 'High entropy alloys and their development as structural materials', *Mater. Sci. Technol.*, 2015, **31**, 1142–1147.
2. T. W. Eagar: 'The future of metals', *Welding J.*, 1970, **70**, 69–71.
3. W. S. Owen: 'Can a simple heat treatment help to save Detroit?', *Met. Technol.*, 1970, **7**, 1–13.
4. R. Kuziak, R. Kawalla and S. Waengler: 'Advanced high strength steels for automotive industry', *Arch. Civ. Mech. Eng.*, 2008, **8**, 103–117.
5. M. I. Khan, M. L. Kuntz, P. Su, A. Gerlich, T. North and Y. Zhou: 'Resistance and friction stir spot welding of DP600: A comparative study', *Sci. Technol. Weld. Join.*, 2007, **12**, 175–182.
6. O. Matsumura, Y. Sakuma and H. Takechi: 'Enhancement of elongation by retained austenite in intercritical annealed 0.4C-1.5Si-0.8Mn steel', *Trans. Iron Steel Inst. of Jpn*, 1987, **27**, 570–579.
7. H. K. D. H. Bhadeshia: 'Bainite in steels: theory and practice', 3rd ed., 2015, Leeds, UK, Maney Publishing.
8. L. Cretteur, A. I. Korkuk and L. Tosal-Martínez: 'Improvement of weldability of TRIP steels by use of in-situ pre- and post-heat treatments', *Steel Res*, 2002, **73**, 314–319.
9. D. C. Saha, S. Han, K. G. Chin, I. Choi and Y. D. Park: 'Weldability evaluation and microstructure analysis of resistance-spot-welded high-mn steel in automotive application', *Steel Research Int*, 2012, **83**, 352–357.
10. C. Beal, X. Kleber, D. Fabregue and M. Bouzekri: 'Liquid zinc embrittlement of a high-manganese-content TWIP steel', *Phil. Mag. Lett.*, 2011, **91**, 297–303.
11. C. Beal, X. Kleber, D. Fabregue and M. Bouzekri: 'Liquid zinc embrittlement of twinning-induced plasticity steel', *Scripta Mater.*, 2012, 1030–1033.
12. C. Beal, X. Kleber, D. Fabregue and M. Bouzekri: 'Embrittlement of a zinc coated high manganese TWIP steel', *Mater. Sci. Eng. A-Struct.*, 2012, **543**, 76–83.
13. C. Beal, X. Kleber, D. Fabregue and M. Bouzekri: 'Embrittlement of a high manganese TWIP steel in the presence of liquid zinc', *Mater. Sci.*, 2012, **706**, Forum, 2041–2046.
14. L. M. Roncery, S. Weber and W. Theisen: 'Welding of twinning-induced plasticity steels', *Scripta Mater*, 2012, **66**, 997–1001.
15. H. Zhao and T. DebRoy: 'Pore formation during laser beam welding of die-cast magnesium alloy AM60B-mechanism and remedy', *Welding J*, 2001, **80**, 204–210.
16. N. J. Kim: 'Critical assessment 6: Magnesium sheet alloys: viable alternatives to steels?', *Mater. Sci. Technol.*, 2014, **30**, 1925–1928.
17. J. D. Robson: 'Critical assessment 9: Wrought magnesium alloys', *Mater. Sci. Technol.*, 2015, **31**, 257–264.
18. H. Zhao, D. R. White and T. DebRoy: 'Current issues and problems in laser welding of automotive aluminium alloys', *Internat. Mater. Rev*, 1999, **44**, 238–266.
19. T. DebRoy and H. K. D. H. Bhadeshia: 'Friction stir welding of dissimilar alloys', *Sci. Technol. Weld. Join.*, 2010, **15**, 266–270.
20. V. Rajinikanth, K. Mukherjee, S. G. Chowdhury, A. Schiebahn, A. Harms and W. Bleck: 'Mechanical property and microstructure of resistance spot welded twinning induced plasticity-dual phase steels joint', *18*, 2013, 485–491.
21. M. Ashfaq and K. J. Rao: 'Comparing bond formation mechanism between similar and dissimilar aluminium alloy friction welds', *Mater. Sci. Technol.*, 2014, **30**, 329–338.
22. S. T. Wei, D. Lv, R. D. Liu, L. Lin, R. J. Xu, J. Y. Guo and K. Q. Wang: 'Similar and dissimilar resistance spot welding of advanced high strength steels: welding and heat treatment procedures, structure and mechanical properties', *Sci. Technol. Weld. Join.*, 2014, **19**, 427–435.
23. S. T. Wei, R. D. Liu, D. Lv, L. Lin, R. J. Xu, J. Y. Guo, K. Q. Wang and X. F. Lu: 'Weldability and mechanical properties of similar and dissimilar resistance spot welds of three-layer advanced high strength steels', *Sci. Technol. Weld. Join.*, 2015, **20**, 20–26.
24. J. Wang, J. C. Feng and Y. X. Wang: 'Microstructure of Al-Mg dissimilar weld made by cold metal transfer mig welding', *Mater. Sci. Technol.*, 2008, **24**, 827–831.
25. Q. Lin, Y. Zhou, R. Cao and J. H. Chen: 'Wetting of steel by Al 4043 alloys in cold metal transfer process', *Sci. Technol. Weld. Join.*, 2015, **20**, 454–459.
26. T. E. Borchers, A. Seid, S. S. Babu, P. Shafer and W. Zhang: 'Effect of filler metal and post-weld friction stir processing on stress corrosion cracking susceptibility of Al-Zn-Mg arc welds', *Sci. Technol. Weld. Join*, 2015, **20**, 460–467.
27. C. Wakabayashi and Y. Miyazaki: 'Strengthening spot weld joint by auto-tempering acceleration at heat affected zone', *Sci. Technol. Weld. Join*, 2015, **20**, 468–472.
28. H. S. Yang and H. K. D. H. Bhadeshia: 'Austenite grain size and the martensite-start temperature', 493–495; 2009, Scripta Mater.
29. L. E. Svensson, L. Karlsson and R. Söder: 'Welding enabling light weight design of heavy vehicle chassis', *Sci. Technol. Weld. Join*, 2015, **20**, 473–482.

30. N. Barnes, T. Joseph and P. F. Mendez: 'Issues associated with welding/surfacing of large mobile mining equipment for use in oil sands applications', *Sci. Technol. Weld. Join*, 2015, **20**, 483–493.
31. S. Wei, R. Liu, D. Lv, L. Lin, X. Lu and S. Ding: 'E?ects of welding parameters on fibre laser lap weldability of galvanized DP 1000 steel', *Sci. Technol. Weld. Join.*, 2015, **20**, 433–442.
32. Y. Chen, J. Chen, B. S. Amirkhiz, M. J. Worswick and A. Gerlich: 'Microstructures and properties of Mg-alloy/DP600 steel dissimilar refill friction stir spot welds', *Sci. Technol. Weld. Join*, 2015, **20**, 494–501.
33. M. Pouranvari, M. A. S. Abadi and P. Marashi: 'Welding metallurgy of stainless steels during resistance spot welding-Part I: The fusion zone', *Sci. Technol. Weld. Join*, 2015, **20**, 502–511.
34. M. Alizadeh-Sh, M. Pouranvari and S. P. H. Marashi: 'Welding metallurgy of stainless steels during resistance spot welding-Part II: The heat affected zone and mechanical performance', *Sci. Technol. Weld. Join*, 2015, **20**, 512–521.
35. K. Chen and Y. Zhang: 'Numerical analysis of temperature distribution during ultrasonic welding process for dissimilar automotive alloys', *Sci. Technol. Weld. Join*, 2015, **20**, 522–531.