International Journal of Research in Engineering, Science and Management
Volume-2, Issue-5, May-2019
www.ijresm.com | ISSN (Online): 2581-5792

An Overview of Enhancement of Mechanical Properties in Weld Joints on Magnesium Alloy: A Review

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***Abstract*: The modern Technology has evolved various techniques to join two metals. Among them to make a permanent joint of two similar or dissimilar metals Welding points are used. In this case to weld magnesium alloy, Friction Stir welding is termed as an effective welding technique which is capable of making a good joint. However, this type of solid state welding is efficient, there are certain parameters should be followed for the improvement of the weld joints. Those parameters to be maintained and sustained for the better strength and hardness of the weld joints are discussed. This paper talks about the various parameters such as welding speed, feed rate, spindle rotation speed. The defects of the welding are investigated by microstructure and SEM results.**

***Keywords*: friction stir welding, magnesium alloy, improvement of weld joints, welding parameters**

1. Introduction

Friction mix welding (FSW) is a strong solid state metal joining procedure which was created and licensed by The Weld Institute of Cambridge, UK, in 1991. Now-a-day's FSW is being used to weld magnesium alloys, Aluminium alloys and other alloys. Structural applications of magnesium alloys are rapidly increasing in automotive and aerospace equipment due to their low-density, and ease of cast ability. Joining of magnesium compounds by regular methods is troublesome because of the few issues, for example, splitting, removal and void in the weld zone. FSW is fit for joining magnesium compound without softening it and along these lines can dispense with issues identified with the cementing. As FSW does not require any filler material in the weld zone, the metallurgical problems associated with it can be eliminated and good quality weld can be obtained. Magnesium alloy AZ31B is an alloy, which has magnesium as its major constitution. Where it is joined to use in variety of application. Here, Friction Stir Welding which is a solid state welding process that uses a non-consumable tool to join the work piece which requires high weld strength. At 1200 rpm of spindle speed, the friction between work piece and the rotating tool leads to the softening of the work piece near the tool. This process of the tool traversing along the weld line creates a plasticification of metal results in solid-state deformation involving dynamic recrystallization of the base material. It is done to reduce the fatigue property of the metal.

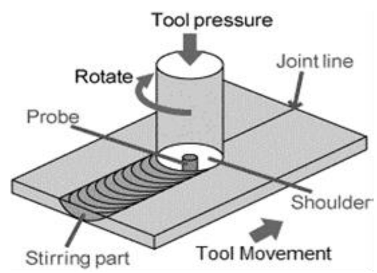

Fig. 1. Friction stir welding

Tensile strength- is an estimation of the power required to pull something, for example, rope, wire, or a basic shaft to the point where it breaks. Here, the ultimate tensile strength of the material is calculated.

Hardness strength- is a proportion of the protection from confined plastic distortion initiated by either mechanical space or scraped spot. It is found to know the maximum hardness of the welded joint.

2. Magnesium and its alloys

Magnesium alloys are broadly divided into

- Mg-Al alloys
- Zr-containing alloys
- Cast Mg alloys
- Die casting

Mordike and Ebert have discussed the major pros and cons of Mg and its alloys which include:

- High specific strength
- Good castability
- Turning and milling
- Weldability
- Resistance to corrosion

A. Major uses

- Various Aircrafts and missile equipment
- Airplanes engine mounts, aircraft control hinges,

fuel tanks and wings

- Automobile wheels, engine housings, transmission cages, engine blocks
- Bicycles and other sports equipment
- Climbing Ladder
- Laptops, cell phones, TV
- Chainsaws, Portable power tools.
- Weedwhacker, hedge clipper.
- Textile and printing machineries
- Steering wheel and frames of sheet

B. Welding parameters

The welding parameters play a key role during all the welding technique including the FSW. The weld quality and the final weld microstructure is influenced by the proper parameters.

Spindle Rotational Speed: The increase in the tool travel speed and decrease in the tool rotational speed will cause a irregular cold weld.

Welding speed: the increased welding speed changes the grain arrangement abruptly.

Tilting angle: Either a constant or variable tilting angle is kept.

Pin Profiles: It plays a vital role in this welding

Axial down force: The generation of frictional heat to soften the material is due the down force.

C. Welding tools

The critical process in the FSW is the tool design as it should have high hardness at the elevated temperature and should sustain till the end. The two important factors to be considered while selecting the tool is weld quality and tool wear, because the weld quality will be affected by the heat dissipation and generation. Usually H13 tool steel is used. The various types of profiles used for pin such as tapered, cylindrical, cylindrical threaded, conical etc. The shape of pin profile ha a great Influence in the final weld microstructure, grain refinement and etc.

Table 1
Mechanical properties of magnesium alloys at room temperature

Property	Unit	AZ91	AM60	AM50	AM20	AS41	AS21	AE42
Ultimate tensile strength	Mpa	240	225	210	190	215	175	230
Yield strength	Mpa	160	130	125	90	140	110	145
elongation	%	3	8	10	12	6	9	10
Elastic modulus	Gpa	45	45	45	45	45	45	45
Brinell hardness		70	65	60	45	60	55	60
Impact strength	J	6.2	17.4	18.33	18.23	4.21	5.3	5

Table 2
Physical properties of magnesium alloys

Property	Unit	Temp(F)	AZ91	AM60	AM50	AM20	AS41	AS21	AE42
Density	g/cucm	68	1.81	1.8	1.77	1.75	1.77	1.76	1.79
Linear Thermal Expansion Coefficient	μm/m	68-212	26	26	26	26	26.1	26.1	26.1
Specific Heat	Kj/kg k	68	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Thermal Conductivity	W/km	68	51	61	65	94	68	84	84
Electrical Conductivity	MS/m	68	6.6	nm	9.1	13.1	nm	10.8	11.7

Table 3
Previous studies on FSW of Mg alloys

Objective	**Work piece material**	**Tool material**	**Year/author**	**Remarks**
Effects of parameters on mechanical property in the FSW weld	AZ31B 400x1000x5mm	M5 guidance High Speed steel	2017/Vedat veli CAY et al	Micro hardness doesn't has major change due to feed rate
Micro structure and tensile property of FSW alloy	AZ31B-H24	Tool steel	2007/N.Afrin et al	Higher weld speed give high hardness ,low rotational speed gives high yield strength
Influence of tensile property ,hardness and microstructure on welding process	AZ31B 240x120x5mm	High Speed Steel	2014/S.Ugender et al	Exhibited Maximum mechanical properties compared to other rotational speeds.
Friction stir welding on magnesium alloy	2024-T3 aluminum alloy and AZ31B 3mm thick plate	Tool steel(SKD61)	2017/C.Murugaraj et al	Tensile strength of the joint is equivalent to 80% of base metal is obtained.
Analysis of defect formation in FSW of MG alloy	AZ31B Magnesium Alloy	H13 Tool Steel	2017/Piyush Gulati et al	Defect free weld were formed at low rotational speed with truncated conocal profile tool
Applying and analysis of FSW of MG alloy by Taguchi Grey based approach	100x50x2 mm ZM21 magnesium alloy	High Speed steel M35	2018/B.Magamai Radj et al	Obtains maximum weld strength of ZM 21 Magnesium alloys
To analyze the micro hardness and mechanical property of cerium added AZ31B Mg alloy	AZ31B Magnesium Alloy 200x60x5 mm	Tool steel	2010/Yu sirong et al	Micro hardness increased from surface to the bottom of the weld
Optimization of AZ91D alloy PVD parameters by Taguchi Grey approach	AZ91D Mg alloy 20x20x5 mm^3	PVD coating	2018/M.Sivapragash et al	Coated materials have high surface properties

Table 3 (Contd.)

Effect of corrosion resistance nickel coating on AZ31B alloy by in-situ shot-peening-assisted-cold spray	AZ31B 25x15x4 mm³	Corrosion resistance coating	2018/Ying-Knag wei et al	High density of dislocation is in part responsible for the slightly lower anticorrosion performance of Ni coating as compared to bulk Ni
Effect of welding parameters on similar friction stir welding joints of AZ31B-O Mg alloy	AZ3B-O Mg alloy 150x75mm	High carbon High Chromium steel	2014/Inderjeet singh et al	High tensile strength which is 91% of the base metal
Analysis of tensile properties and strain hardening behavior of double-sided arc welded and FSW AZ31B mg alloy	2mm thick AZ31B-H24 Mg alloy	Tool steel H24	2010/S.M.Choudhury et al	FSW resulted in recrytalized and relatively small grains in the SZ and TMAZ
Evaluation of FSW process of dissimilar metals of 6061-T6 Al alloy to AZ31B Mg alloy	AZ31B-O Mg alloy 200x45x3.0 mm	H13 tool steel	2015/Banglong Fu et al	The sufficient intermixing between dissimilar materials and the intermediate heat input were helpful to the high weld properties.
Electrochemical corrosion behavior of stir zone of FSW dissimilar joints of AA6061 aluminium-AZ31B mg alloy	AA6061-T6 Al alloy 150 mmx75 mm	High speed steel	2016/R.Kamal jayaraj et al	Corrosion rate decreases with an increase in exposure time
Improvement of micro structural and tensile properties of AZ31B Mg alloy by Stationary shoulder friction stir welding	AZ31B 200x90x6.35 mm³	Conventional FSW tool	2019/Wenya li et al	Smooth surface of alloy is produced in SSFSW method
Conversion of FSW of Mg alloy AZ31B to Al alloy 5083	AZ31B 12mm AA 5083 200mm	Tool steel	2003/A.A.McLean et al	Visually sound and no ductile welds are produced
Proper Tool pin profile selection for FEW of AZ31B alloy	AZ31B Magnesium Alloy 220x75x6 mm	High carbon steel High speed steel Stainless steel	2009/G. Padmanaban et al	Defect free fine equiaxed grains nugget region, higher hardness and tesnile property is obtained
Effect of friction stir processing on the superplastic formomg of AZ31B alloy	AZ31 B Alloy Plate	Super Plastic Forming Tool	2014/ S. Ramesh Babu et al	Super plastic foring time decreased than that of the non-friction stir processed material
Analysis of dissimilar FSW of Al and Mg alloy	AZ31B Magnesium alloy and A5052-H aluminum alloy plate. plate thickness 3 [mm]	JIS SKD61 Tool steel	2008/ Taiki Morishige et al	Higher joint efficiency is obtained
Behavior analysis of stress corrosion cracking of peened FSW 2195 Al alloy	Aluminum Alloy 2195 1.25 Thickness	Tool Steel	2009/ Omar Hatamleh et al	High tensile property is obtained than unpeened sample
Improvement of FSW A6061-T6 Al alloy by laser peening without coating	A6061-T6 aluminum alloy 300x60x3mm	Carbon steel High Strength Steel	2012/ Y. Sano et al	Higher fatigue performance can be expected
Effect of Ultrasonic spot welded Al-Al joint in microdtructure and mechanical properties	Aluminum 2219 100x25x1.25mm	High speed steel	2019/ Zeng-Lei Ni et al	Different thickness material are joined and fabricated
Analysis of FSW reinforcement technique on 5754 alloy	Aluminum Alloy 5754	H 13 Tool	2017/ Hossein Andalib et al	FFSSW approach with the concave tool was increased the joint strength for about 37% higher than CFSSW strength
Improvement of strength of joint in Ti-6Al-4V alloy to type-718 nickel based alloy using the Au-Ni interlayer	Type-718 nickel-based alloy and Ti-6Al-4V alloy	Tool Steel	2018/ Tomo Ogura, Keisuke Miyoshi et al	High tensile strength along the formation of a thin intermediate layer.
Effect of Submerged friction stir welding on 7050 Al alloy butt joints on weld temperature distribution and mechanical properties	Aluminum Alloy 7050	H 13 Tool Steel	2011/ Rui-dong Fu et al	Mechanical properties of the welded joints in hot water are the best amongst all weld joints tested
Strength and ductility improvement of Al alloy joints via rapid cooling during FSW	20 mm thick AA2219-T62 Aluminum Alloy	Tool Steel	2012/ W.F. Xu et al	Compared to air cooling ,water cooling during FSW improves both the strength and ductility
Improvement of weld strength of Mg to Al via tin interlayer during ultra sonic spot welding	Aluminum 5754 Magnesium alloy AZ31B (80X15X3mm)	H 24 Tool	2012/ V. K. Patel et al	Maximum lap shear strength and failure energy of Mg to Al with an Sn interlayer is achieved
Microstructure and performance analysis for Al welds produced by magnetic field assisted laser welding	Aluminum Alloy	Tool Steel	2018/ Fei Yana et al	Joint with good weld quality can be achieved with reduced susceptibility and improved shear strength
Improvement of fatigue strength for high strengthsteel welded joints	Aluminum and Magnesium alloy	High Strength Steel	2012/ Halid Can Yildirim et al	An increase in fatigue strength and yield strength was found
Analysis of disiimilar welding techniques for Mg to Al alloy	Aluminum alloy 1050 and Magnesium alloy AZ31	Rotating tool	2014/ Liming Liu et al	Impacts the dissemination and the thickness of the Mg-Al alloy and increases the mechanical property of the joint

Table 3 (Contd.)

Investigation of Fatigue property of AA2024-T351	AA2024-T351 500x65x6 mm	Tool steel	2018/Miodrag milcic et al	Minimun friction heat generated and high joint efficiency is obtained

3. Conclusion

Thus there are several experiments that show us the parameters and methods to improve the weld joint. Friction stir welding can be done effectively for the magnesium alloy by maintaining the different tool parameters, it is also effective in joining different alloys with Mg. An effective welding with a high mechanical and micro structural property can be obtained. It shows us that right from the tool selection and the PWHT selection has a major influence in the efficiency of the weld joint. As per the study 1000rpm of tool rotation speed, 22mm/min welding speed and 0.10 plunging depth are the optimum process parameters to give maximum weld strength for 2mm thick magnesium alloy.

References

[1] Vedat Veli ÇAY, Nida KATI, Sermin Ozan, Veysel YAPICI Investigation of effects of different Parameters on Mechanical Properties in Friction Stir Welding of AZ31B Magnesium alloy, 2017.
[2] Inderjeet Singh, Gurmeet Singh Cheema, Amardeep Singh Kang An experimental approach to study the effect of welding parameterson similar friction stir welded joints of AZ31B-O Mg alloy. 12th global congress on manufacturing and management, GCMM 2014
[3] N. Afrin, D.L. Chena, X. Cao, M. Jahazi Microstructure and tensile properties of friction stir welded AZ31B magnesium alloy; accepted 6 March 2007 Materials Science and Engineering A 472 (2008) 179–186
[4] S. Ugender, A. Kumar and A. Somi Reddy Influence of Welding Processes on Tensile Properties, Microstructure, and Hardness of Friction Stir Welded AZ31B Magnesium Alloy. Bonfring International Journal of Industrial Engineering and Management Science, Vol. 4, No. 2, May 2014
[5] Banglong Fu, Guoliang Qin, Fei Li, Xiangmeng Meng, Jianzhong Zhang, Chuansong Wu Friction stir welding process of dissimilar metals of 6061-T6aluminum alloy to AZ31B magnesium alloyBanglong Journal of Materials Processing Technology 218 (2015) 38–47
[6] Piyush Gulatia, F, Dinesh Kumar Shuklac, Akash Guptab Defect formation analysis of Friction Stir welded Magnesium AZ31B alloy Materials Today: Proceedings 4 (2017) 1005–1012
[7] B. Magamai Radj and T. Senthivelan Analysis of mechanical properties on friction stir welded magnesium alloy by applying Taguchi Grey based approach Materials Today: Proceedings 5 (2018) 8025–8032
[8] Ying-Kang Wei, Yu-Juan Li, Yue Zhang, Xiao-Tao Luo, Chang-Jiu LiCorrosion resistant nickel coating with strong adhesion on AZ31Bmagnesium alloy prepared by an in-situ shot-peening-assisted cold spray. State Key Laboratory for Mechanical Behavior of Materials, School of Materials Science and Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, PR China
[9] Mustafa A. Abdulstaara, , Khaled J. Al-Fadhalah, Lothar Microstructural Variation through Weld Thickness and Mechanical Properties of Peened Friction Stir Welded 6061 Aluminum Alloy Joints, 2017.
[10] M. Sivapragash, P. Kumaradhas, S.C. Vettivel, B. Stanly Jones Retnam Optimization of PVD process parameter for coating AZ91D magnesium alloy by Taguchi grey approach. Journal of Magnesium and Alloys 6 (2018) 171–179.
[11] G. Padmanaban, V. Balasubramanian Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy – An experimental approach. Materials and Design 30 (2009).
[12] S. Ramesh Babu, V.S. Senthil Kumar, L. Karunamoorthy, G. Madhusudhan Reddy Investigation on the effect of friction stir processing on the superplastic forming of AZ31B Accepted 1 July 2013Materials and Design 53 (2014) 338–348.
[13] Taiki Morishige, Atsushi Kawaguchi, Masato Tsujikawa1, Makoto Hino, Tomotake Hirata and Kenji Higashi, Dissimilar Welding of Al and Mg Alloys by FSW, 2007.
[14] Omar Hatamleh, Preet M. Singh, and Hamid Garmestani Stress Corrosion Cracking Behavior of Peened Friction Stir Welded 2195 Aluminum Alloy Joints.
[15] Y. Sano K. Masaki, T. Gushi, T. Sano Improvement in fatigue performance of friction stir welded A6061-T6 aluminum alloy by laser peening without coating Materials and Design 36 (2012) 809–814.
[16] Zeng-Lei Ni and Fu-Xing Ye Microstructure and Mechanical Properties of an Ultrasonic Spot-Welded Aluminum-to-AluminumJoint: Response to Interlayer Thickness, 2019.
[17] Hossein Andalib, Mohammadreza Farahani and Moeen Enami Study on the new friction stir spot weld joint reinforcement technique on 5754 aluminum; 2017
[18] Tomo Ogura, Keisuke Miyoshi, Takahiro Matsumura, Tomoya Imai and Kazuyoshi Saida Improvement of joint strength in dissimilar friction welding of Ti-6Al-4V alloy to type-718 nickel-based alloy using the Au–Ni interlayer.
[19] Rui-dong Fu Zeng-qiang Sun, Rui-cheng Sun , Ying Li , Hui-jie Liu , Lei Liu an Improvement of weld temperature distribution and mechanical properties of 7050 aluminum alloy butt joints by submerged friction stir welding Accepted 13 June 2011 Materials and Design 32 (2011) 4825–4831.
[20] W.F. Xua, J.H. Liua, D.L. Chenb, G.H. Luanc, J.S. Yaod Improvements of strength and ductility in aluminum alloy joints via rapid cooling during friction stir welding Accepted 28 March 2012 Materials Science and Engineering A 548 (2012) 89– 98
[21] V. K. Patel, S. D. Bhole and D. L. Chen Improving weld strength of magnesium to aluminium dissimilar joints via tin interlayer during ultrasonic spot welding Science and Technology of Welding and Joining 2012.
[22] Fei Yan, Xianwei Wangd, Fang Chaia,b, Huijuan Maa Linli Tiana Xiaozhong Due, Chunming Wang, Wei Wanga,bImprovement of microstructure and performance for steel/Al welds produced by magnetic field assisted laser welding Optics and Laser Technology 113 (2019) 164–170
[23] Halid Can Yildirim, Gary B. Marquis Fatigue strength improvement factors for high strength steel welded joints treated by high frequency mechanical impact International Journal of Fatigue 44 (2012) 168–176
[24] Liming Liu, Daxin Ren and Fei Liu A Review of Dissimilar Welding Techniques for Magnesium Alloys to Aluminum Alloys. Accepted: 25 April 2014
[25] V.Naveenprabhu and M.Suresh, "Performance evaluation of tube-in-tube heat exchanger using nanofluids", Applied Mechanics and Materials, vol. 787, , pp. 72–76. (2015).
[26] F. Justin Dhiraviam, V. NaveenPrabhu, T. Suresh, and C. Selva Senthil Prabhu, "Improved Efficiency in Engine Cooling System by Repositioning of Turbo Inter Cooler," Applied Mechanics and Materials, vol. 787, (2015), pp. 792–796
[27] P.AshokaVarthanan, G.Gokilakrishnan, (2018). Simulation Based Swarm Intelligence to Generate Manufacturing-distribution Plan for a Bearing Industry under Uncertain Demand and Inventory Scenario. International Journal of Pure and Applied Mathematics, 119, 2117-2134.
[28] Balasubramani, S., & Balaji, N. (2016). Investigations of vision inspection method for surface defects in image processing techniques-a review. Advances in Natural and Applied Sciences, 10(6 SE), 115-120.
[29] Venkatesha, S., & Sakthivelb, M. (2017). Numerical investigation and optimization for performance analysis in Venturi inlet cyclone separator. Desalination and water treatment, 90, 168-179.
[30] R.Z.Wang, J.Y.Wu, Y.X.Xu, Y.Teng, W.Shi. "Spiral plate heat exchanger". "Energy Conversion and Management", Volume 42 (Issue 2), Pp. 13-23. (2001)
[31] Lon E. Bell. "Electricity production by heat recovery in air conditioning and refrigeration". "Science", Volume 321, Issue 5895Volume 4(Issue 6), Pp. 145-146. (2008)

[32] ZhaolinGu, Hong juan Liu, Yun Li. “Heat recovery system for air conditione”. “Applied Thermal Engineering”, Volume 24(Issue 17-18), pp. 2511-2526. (2004).
[33] Hailei Wang. “Performance of a combined organic Rankine cycle and vapor compression cycle for heat activated cooling”. “Energy” Volume 36 (Issue 1), Pp. 447-458. (2011).
[34] John W Coleman, SrinivasGarimella.” Two-phase flow regimes in round, square and rectangular tubes during condensation of refrigerant R134a”. “International Journal of Refrigeration”, Volume 26(Issue 1), Pp. 117-128. (2003).
[35] MostafaA.Abd El-Baky. “Heat pipe heat exchanger for heat recovery in air conditioning”. “Applied Thermal Engineering”, Volume 27 (Issue 4), pp. 795-801. (2007).
[36] V. NaveenPrabhu, K. SaravanaKumar, T. Suresh and M. Suresh," Experimental investigation on tube-in-tube heat exchanger using nanofluids", Advances in Natural and Applied Sciences, Vol 10(7), pp. 272-278. (2016).
[37] N. Manigandan, V.Naveenprabhu and M.Devakumar, “Design and Fabrication of Mechanical device for EffectiveDegreasing in Roller Bearing” Science direct-Procedia Engineering, 97 (2014) pp.134 – 140
[38] N Manigandan, V NaveenPrabhu and M Suresh, “Experimental Investigation of a Brazed Chevron Type Plate Heat Exchanger,” International Journal of Science Technology & Engineering, Vol. 1 (12) , (2015), pp.1-7.
[39] V NaveenPrabhu and N Manigandan, “Design and Fabrication of Solar Transport Vehicle” IOSR Journal of Mechanical and Civil Engineering, pp. 14-19.
[40] Y.Sureshbabu and P.AshokaVarthanan, Study the emission characteristics of catalytic coated piston and combustion chamber of a four stroke spark ignition (SI) engine, Journal of Chemical and Pharmaceutical Sciences, JCHPS Special Issue 4: December 2014, pp-126-127.
[41] Venkatesh, S., Sakthivel, M., Sudhagar, S., & Daniel, S. A. A. (2018). Modification of the cyclone separator geometry for improving the performance using Taguchi and CFD approach. Particulate Science and Technology, 1-10.
[42] Jeyakumar, R., Sampath, P. S., Ramamoorthi, R., & Ramakrishnan, T. (2017). Structural, morphological and mechanical behaviour of glass fibre reinforced epoxy nanoclay composites. The International Journal of Advanced Manufacturing Technology, 93(1-4), 527-535
[43] Thirumalaisamy, R., &Pavayee Subramani, S. (2018). Investigation of Physico-Mechanical and Moisture Absorption Characteristics of Raw and Alkali Treated New Agave Angustifolia Marginata (AAM) Fiber. Materials Science, 24(1), 53-58.
[44] Kumar, R. S., Alexis, J., &Thangarasu, V. S. (2017). Optimization of high speed CNC end milling process of BSL 168 Aluminium composite for aeronautical applications. Transactions of the Canadian Society for Mechanical Engineering, 41(4), 609-625.
[45] Kumar, S., Alexis, J., &Thangarasu, V. S. (2016). Prediction of machining parameters for A91060 in end milling. Advances in Natural and Applied Sciences, 10(6 SE), 157-164.
[46] Subramaniam, B., Natarajan, B., Kaliyaperumal, B., &Chelladurai, S. J. S. (2018). Investigation on mechanical properties of aluminium 7075-boron carbide-coconut shell fly ash reinforced hybrid metal matrix composites. China Foundry, 15(6), 449-456.
[47] Balasubramani, S., Dhanabalakrishnan K. P.,Balaji, N. (2015) Optimization of Machining parameters in Aluminium HMMC using Response Surface Methodology. International journal of applied engineering research, 10(20), 19736-19739.
[48] Callender. “Aluminium Foil for Insulation”. “Architectural Forum”, Volume 60(Issue 2), Pp. 67-71. (2014)
[49] Sheng-shanBi. “Application of nanoparticles in domestic refrigerators”. “Applied Thermal Engineering”, Volume 28(issue 14-15), Pp. 1834-1843. (2008).
[50] Marcia LHuber, James FEly. “A predictive extended corresponding states model for pure and mixed refrigerants including an equation of state for R134a”. “International Journal of Refrigeration”, Volume 17 (Issue 1), Pp. 18-31. (1994).
[51] Ramakrishnan, T., & Sampath, P. S. (2017). Dry Sliding Wear Characteristics of New Short Agave Angustifolia Marginata (AAM) Fiber-Reinforced Polymer Matrix Composite Material. Journal of Biobased Materials and Bioenergy, 11(5), 391-399.
[52] Kumar, R. S., Alexis, J., & Thangarasu, V. S. (2017). Optimization of high speed CNC end milling process of BSL 168 Aluminium composite for aeronautical applications. Transactions of the Canadian Society for Mechanical Engineering, 41(4), 609-625
[53] Kumar, S. R., Alexis, J. S., & Thangarasu, V. S. (2017). Experimental Investigation of Influential Parameters in High Speed Machining of AMS 4205. Asian Journal of Research in Social Sciences and Humanities, 7(2), 508-523.
[54] Ganeshkumar, S., Thirunavukkarasu, V., Sureshkumar, R., Venkatesh, S., Ramakrishnan, T. Investigation of wear behaviour of silicon carbide tool inserts and titanium nitride coated tool inserts in machining of en8 steel.
[55] Kumar, S., Alexis, J., & Thangarasu, V. S. (2016). Prediction of machining parameters for A91060 in end milling. Advances in Natural and Applied Sciences, 10(6 SE), 157-164
[56] Kumar, R. S., Thangarasu, V. S., & Alexis, S. J. (2016). Adaptive control systems in CNC machining processes--a review. Advances in Natural and Applied Sciences, 10(6 SE), 120-130.
[57] Kumar, S., Alexis, J., & DhanabalakrishnanK.P (2015). Application of ga & ann for the optimization of cutting parameters for end milling operation- a comparison. International Journal of Applied Engineering Research, 10(20), 18092-18107.
[58] Ramakrishnan, T., & Pavayee Subramani, S. (2018). Investigation of Physico-Mechanical and Moisture Absorption Characteristics of Raw and Alkali Treated New Agave Angustifolia Marginata (AAM) Fiber. Materials Science, 24(1), 53-58.
[59] Ramakrishnan, T., & Sampath, P. S. (2017). Dry Sliding Wear Characteristics of New Short Agave Angustifolia Marginata (AAM) Fiber-Reinforced Polymer Matrix Composite Material. Journal of Biobased Materials and Bioenergy, 11(5), 391-399.
[60] Jeyakumar, R., Sampath, P. S., Ramamoorthi, R., & Ramakrishnan, T. (2017). Structural, morphological and mechanical behaviour of glass fibre reinforced epoxy nanoclay composites. The International Journal of Advanced Manufacturing Technology, 93(1-4), 527-535.
[61] Ramakrishnan, T., & Sampath, P. S. (2017). Experimental investigation of mechanical properties of untreated new Agave Angustifolia Marginata fiber reinforced epoxy polymer matrix composite material. Journal of Advances in Chemistry, 13(4), 6120-6126.
[62] Ramamoorthi, R., Jeyakumar.R, & Ramakrishnan,T. (2017). Effect of Nanoparticles on the Improvement of Mechanical Properties of Epoxy Based Fiber – Reinforced Composites - A Review. International Journal for Science and Advance Research in Technology, 3(11), 1251- 1256.
[63] Ramakrishnan, T., Sampath, P. S., & Ramamoorthi, R. (2016). Investigation of Mechanical Properties and Morphological Study of the Alkali Treated Agave Angustifolia Marginata Fiber Reinforced Epoxy Polymer Composites. Asian Journal of Research in Social Sciences and Humanities, 6(9), 461-472.
[64] Ramakrishnan, T & Sampath, P.S. (2016). Thermogravimetric Analysis (TGA) and the Effect of Moisture Absorption on the Mechanical Properties of New Agave Angustifolia Marginata 3 Fiber (AAMF) Reinforced Epoxy Polymer Composite Material, International Journal of Printing, Packaging & Allied Sciences, 4(5), 3245-3256.
[65] Ramakrishnan, T., Sathish, K., Sampath, P. S., & Anandkumar, S. (2016). Experimental investigation and optimization of surface roughness of AISI 52100 alloy steel material by using Taguchi method. Advances in Natural and Applied Sciences, 10(6 SE), 130-138.
[66] Sathish, K., Ramakrishnan, T., & Sathishkumar, S. (2016). Optimization of turning parameters to improve surface finish of 16 Mn Cr 5 material. Advances in Natural and Applied Sciences, 10(6 SE), 151-157.
[67] S. Karthik Raja S.Balasubramani, S.Venkatesh, T.Ramakrishnan (2015). Effect Of Cryogenic Tempering On Steel,International Journal of Mechanical and Civil Engineering, 2 (6), 98-113.
[68] Venkatesh, S., &Sakthivel, M. (2017). 'Numerical Investigation and Optimization for Performance Analysis in Venturi Inlet Cyclone Separator', Desalination and Water treatment, Vol. 90, No. 9, pp. 168-179.
[69] Venkatesh, S., Sakthivel, M., Sudhagar, S.,&Ajith Arul Daniel, S.(2018). 'Modification of the cyclone separator geometry for improving the performance using Taguchi and CFD approach', Particulate Science and Technology,

[70] Venkatesh, S., Bruno Clement, I., Avinasilingam, M., &Arulkumar, E. (2017). "Design of Experiment Technique for Improving the Performance of Stirling Engine", International Research Journal of Engineering and Technology, Vol. 4, No. 5, pp. 62-65.

[71] Venkatesh, S., Balasubramani, S., Venkatramanan, S., &Gokulraj, L. "Standardization of hpx spool for lead time reduction of string test", Journal of Mechanical and Civil Engineering,Vol. 2, No. 6, pp. 62-79.

[72] Kousalya Devi, S., Venkatesh, S., &Chandrasekaran. P. (2015). "Performance Improvement of Venturi Wet Scrubber,"Journal of Mechanical and Civil Engineering, Vol. 2, No. 4, pp. 1-9.

[73] Arunkumar, P., Dhachinamoorthi, P., Saravanakumar, K., &Venkatesh, S. (2014). "Analysis and Investigation of Centrifugal Pump Impellers Using CFD," Engineering Science and Technology: An International Journal, Vol. 4, No. 4, pp. 112-117.

[74] Dhanabalakrishnan,K.P., Abuthakir, J., Subramanian, R., Venkatesh, S. (2015)."Evaluation of Tensile Properties of Particulate Reinforced Al-Metal Matrix Composites," Engineering Science and Technology: An International Journal, Vol. 5, No. 1, pp. 173-175.

[75] F. Justin Dhiraviam, V.Naveenprabhu, M.Santhosh," Study the Effects of Solar Assisted Vapour Compression Air Conditioning System for Winter Applications", International Journal for Scientific Research & Development|, Vol 4(11),(2017), pp. 505-508

[76] V. NaveenPrabhu, K. SaravanaKumar, T. Suresh and M. Suresh," Experimental investigation on tube-in-tube heat exchanger using nanofluids", Advances in Natural and Applied Sciences, Vol. 10(7),(2016), pp. 272-278

[77] V Naveenprabhu, D Mugeshkumaar, KB Pravin, V Ranjith, S Sanjay Arthanari Swamy," A Review of Evaporative Cooling of Finned and Non-Finned Heat Exchanger on Condenser", International Journal for Scientific Research & Development, Vol 6(2), (2018), pp. 459-461.

[78] V.Naveenprabhu, F.Justin Dhiraviam, A. Vimal, K. Kumarrathinam," Design Of Common Header Line For Reduction Of Process Time In Pump Testing", International Research Journal of Engineering and Technology, Vol 4(1),(2017), pp. 969-975.

[79] B.Santhosh Kumar, et.al," Effect of Load on Joint Efficiency and Hardness in Friction Stir Welding of AA6061 & AA6063 Aluminium Alloys.", International Journal for Scientific Research & Development|, Vol 6(2),(2018), pp. 2669-2771.

[80] Ganesh Kumar, S & Thirunavukkarasu, V 2016, Investigation of Tool Wear and Optimization of Process Parameters in Turning of EN8 and EN 36 Steels, Asian Journal of Research In Social Sciences And Humanities. vol. 6, no.11, pp. 237 – 243.

[81] Kumar, S. D., Kumar, S. S., & Kumar, K. A. (2018). Investigation of Forced Frequency in a Commercial Vehicle Suspension System. Mechanics and Mechanical Engineering, 22(4), 967-974

[82] Balasubramani, S., & Balaji, N. (2016). Investigations of vision inspection method for surface defects in image processing techniques-a review. Advances in Natural and Applied Sciences, 10(6 SE), 115-120.

[83] Balasubramani, S., Dhanabalakrishnan K. P., Balaji, N. (2015) Optimization of Machining parameters in Aluminium HMMC using Response Surface Methodology. International journal of applied engineering research, 10(20), 19736-19739.

[84] Subramaniam, B., Natarajan, B., Kaliyaperumal, B., & Chelladurai, S. J. S. (2018). Investigation on mechanical properties of aluminium 7075-boron carbide-coconut shell fly ash reinforced hybrid metal matrix composites. China Foundry, 15(6), 449-456.

[85] Sureshbabu, Y., & AshokaVarthanan, P. Study the emission characteristics of catalytic coated piston and combustion chamber of a four stroke spark ignition (SI) engine. Journal of Chemical and Pharmaceutical Sciences.

[86] Sureshbabu, Y., & AshokaVarthanan, P. (2018) Study the emission characteristics of catalytic coated piston and combustion chamber of a four stroke spark ignition (SI) engine. International Journal for Scientific Research & Development, 6(02), 1981-1983.