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A Review on Fabrication and Mechanical Characterization of Particulate Reinforced Al-7075 Metal Matrix Composites/Hybrid Composites

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ABSTRACT

Nowadays almost all the industries around the globe are using the composites instead of ferrous alloys to produce the low weight mechanical elements/components without scarifying the properties of the materials being used. The aluminium is a best substitute to conventional materials due to their ‘low weight’, ‘corrosion resistance’, ‘high strength’ and ‘low density’ properties/ characteristics. Aluminium Metal Matrix (AMM) composites are the trending materials to be used in various engineering applications having the capacity to accomplish the required demand. The specific/ desired properties can be obtained by adding the reinforcement fillers like SiC, TiC, B4C, Tungsten Carbide, Fe, stainless steel, Oxides, Nitrides, Molybdenum Disulphide, fly ash, Graphite, red mud, Agro waste powders like coconut shell ash (CSA), rice husk ash (RHA), palm kernel shell ash (PKSA), bagasse ash, maize stalk ash, been shell waste ash, Bamboo leaf ash, corn cob ash, aloe Vera powder, Egg shell ash and snail shell ash etc., to the Aluminium matrix material. Many researchers have studied the effect of reinforcing materials to the Aluminium matrix to enrich the ‘metallurgical and mechanical’ characteristics with the modification in texture and surface of the composite. The present review article aims to study the technique of stir casting to fabricate Al-7075 based metal matrix and hybrid composites with the incorporation of above reinforcement particulates and how the addition of above reinforcing materials to Al-7075 matrix has enhanced the properties like compressive strength, impact strength, hardness, fracture toughness, wear resistance and corrosion resistance with the reduction in density of composite. The influence of type, size and shape of the reinforcing materials on characteristics of Al-7075 metal matrix composites and the possible reasons of increase/decrease in physical/ mechanical characteristics are studied.

1. Introduction

The industries are rapidly shifting toward the use of composites because of their improved properties, lower cost, environmental friendliness and lighter weight in comparison, growing its desirability to substitute the traditional ones [1].

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The various composites/amalgams are prepared by adding the altered reinforcements of numerous features to the metals to overcome the constraints imposed by conservative materials with a greater weight, lower physical/ mechanical properties. Composites have superior mechanical properties in comparison with the conventional materials [2,3]. In recent years researchers are doing the research activities on development and potential usage of 'metal matrix composites' in various fields of automobile/aircraft components manufacturing/aerospace, marine fittings, electrical fittings/connectors, Hang glider airframes, rock climbing equipment, bicycle components and pipelines etc., and they turned to Al-7075 metal matrix hybrid composites as they are giving high strength to weight ratio (HSWR), high wear/ corrosion resistance, improved electrical performance, stiffness and reduced density. The enhancement in above properties is due to the reinforcement of particulates as well as presence of zinc up to 6.1% in Al-7075 alloy. The chemical composition of Al-7075 is as follows: Zinc (Zn): 6.012 %, Magnesium (Mg): 1.681 %, Copper (Cu): 1.812%, Mn/Cr/ Fe/ Si/ Ti: less than 0.5% and Aluminium (Al): 90 %. Al-7075 alloy exhibits Tensile Strength of 572 MPa, Yield Strength of 503 MPa and elongation of 10 % to 11 % [4]. Al based hybrid metal matrix composites (AHMMC) are present generation composites reinforce with two or more particulate reinforcements known as Hybridization for further enhancement of properties compared to conventional metal matrix composites. It also lowers the manufacturing cost of composites.

2. Processing of Al-7075 Matrix Composites

So many processing techniques like powder metallurgy, liquid infiltration, diffusion bonding, squeeze casting, laser composite surfacing and stir casting are available. The Al-7075 based composites with reinforcement are prepared by stir casting method as shown in Figure 1, which is one of the most economical and advanced method of fabrication. The systematic procedure of stir casting is as follows [4]:

i. Al-7075 alloy is melted above its melting temperature in a graphite crucible.
ii. Pre heated Reinforcing material is added/ mixed to Al-7075 alloy when its temperature reduces to semi solid temperature.
iii. Reheating the mixture with continuous stirring to attain the refined microstructure as well as uniform distribution of reinforcement particulates throughout the matrix material. The parameters to be considered for mixing the matrix and reinforcement to refine the microstructure are relative density of materials, geometry of the stirrer, Temperature of melting and rate of solidification.
iv. Molten metal is poured in to die to prepare the specimens as per ASTM Standards.
v. Testing of samples under experimental setups for characterization and micro structures.

3. Properties of Al-7075 Metal Matrix Composites

The properties of Al-7075 metal matrix composites to be studied are

i. Physical Properties like density, temperature distribution, Thermal properties and electrical conductivity
ii. Mechanical Properties like Tensile Strength, Compressive Strength, Hardness, Impact Strength and fatigue strength
iii. Tribological Properties like wear. From the past investigations of researchers, it is observed that the mechanical properties of Al-7075 composites were enhanced with the

reduction in weight, wear and corrosion compared to Al-7075 alloy. Further enhancement in properties has been noticed with the addition of two or more filler particulates as reinforcement [5-7].

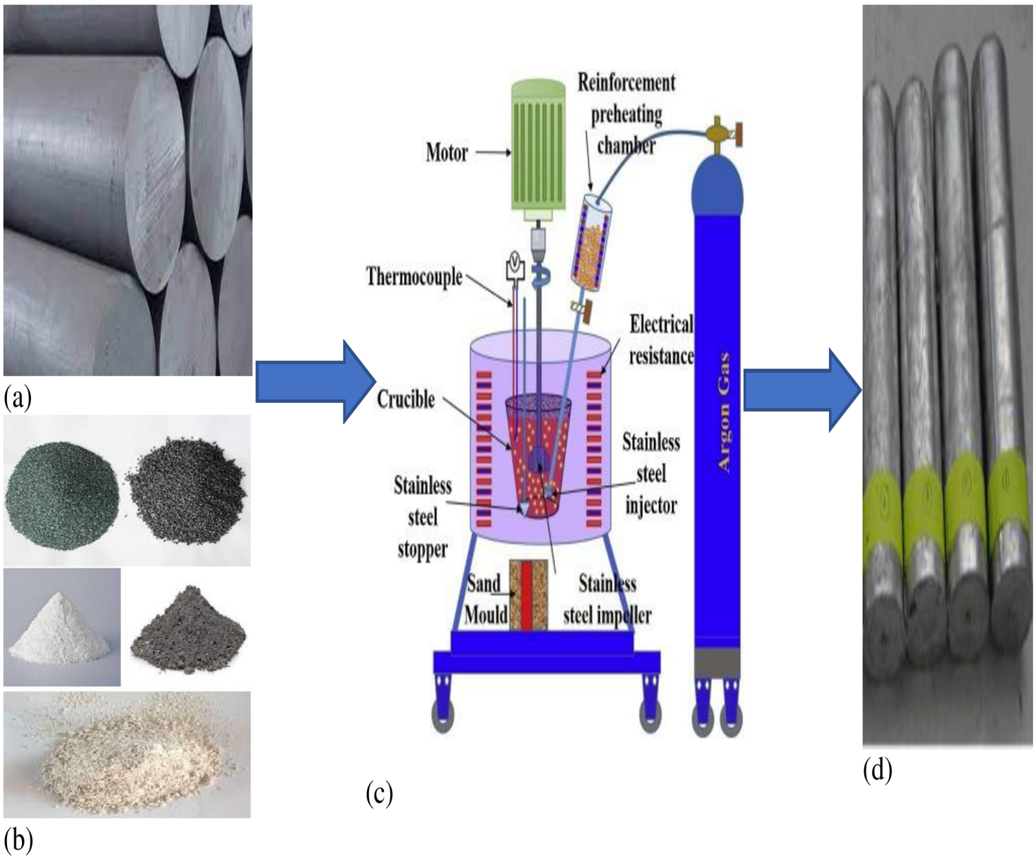

Fig. 1. (a) Al-7075 Alloy, (b) Particulate Reinforcements, (c) Stir Casting Setup with sand mold and (d) Casted Specimens

4. Review on Mechanical Properties of Al-7075 Metal Matrix Hybrid Composites

Amit Raturi *et al.,* [8] fabricated the Al-7075 based Al_2O_3 Nano fillers reinforced (at 3, 5 and 7Wt. %) composites by stir casting method to study the mechanical, tribological and structural behaviour. The hardness values of the composites/compounds are improved with the increase in addition of Al_2O_3 filler and the maximum value of 129 BHN is observed in the composites filled with 7Wt. % of Al_2O_3. The Tensile Strength, Flexural Strength and Impact Strength of the compounds/ composites have been improved with the increase in wt. % of the filler up to 5 Wt. % and the properties are decreased with the further addition of Al_2O_3 at 7Wt.%. This may be due to presence porosity at high levels, uneven distribution of fillers and cluster formation.

R Pramod *et al.,* [9] have done the experimentation work on Al_2O_3 reinforced Al-7075 based composites and the mechanical properties were enhanced with the accumulation/ addition of filler when compared with pure Al-7075 alloy.

Diptikanta Das *et al.,* [10] did the investigations to find mechanical properties of SiC filledAl-7075 composites. It is observed that with the increase in addition of filler content from 0 to 25Wt. % and decrease in particle size of the filler at four levels (0, 5, 15 and 25Wt. % of SiC fillers) the micro hardness has been enhanced with the reduction in ductility. Reduction in yield strength is observed with the rise in filler content as well as improvement in yield strength is observed with the reduction in particle size of the reinforcement/ strengthening filler. The ultimate tensile strength (UTS) is increased with the addition/accumulation of reinforcement filler up to 15Wt. % and reduced at 25Wt. % and with the reduction in particle size of the reinforcement filler. All the above properties were enhanced for the heat-treated samples compared to casted Al-7075 composites.

Manoj Singla *et al.,* [11] varied the SiC reinforcement with 10Wt. % and 15Wt. % to prepare the composite by stir casting method and observed that the mechanical properties were enhanced but density is reduced with the increase in addition of the reinforcement filler.

Chandana Sri S. *et al.,* [12] have done the work on manufacturing and characterization of SiC (at 5Wt. %) and Graphite (at 2 Wt. % and 4Wt. %) reinforced Al-7075 hybrid composites. It is observed that the micro hardness of hybrid composite at 2 Wt. % of the Graphite has been improved by 64% compared to the base Al-7075 alloy, but the hybrid composite filled with 4Wt. % of the Graphite has shown only 16% increase in hardness over Al-7075 alloy. Here the decrease in hardness value is due to high level of porosity. The same trend of improvement is observed for impact strength also with 55% and 40% improvement in hybrid composites/ compounds strengthened/ reinforced with 2Wt. % and 4Wt. % Graphite filler over Al-7075 base alloy.

Atla Sridhar *et al.,* [13] successfully prepared the Al-7075 based hybrid composites/ compounds strengthened/ reinforced with SiC/ mixture of SiC and Graphite by 'powder metallurgy' technique and they found the mechanical and then wear properties. The hardness of the Al-7075 composite reinforced with 5Wt. % SiC is enhanced compared to Base Al-7075 alloy but it is reduced when the hybridization of composite is done with the addition of 5Wt. % of Graphite to Al-7075 composite (Al-7075+ 5% of SiC+5% of Graphite). Increase in addition of graphite to composite reduces the mechanical properties where as more SiC content in composite results in difficulty in machining.

K. Maruthi Varun *et al.,* [14] made the investigation on mechanical properties of SiC (3, 6 and 9Wt. %) and MoS_2 (1Wt. %) reinforced hybrid composites with Al-7075 as base metal and they observed that the values of 'Tensile strength' and 'hardness' were enhanced with the rise in Wt. % of SiC reinforcement from 3% to 9%. S. Suresh *et al.,* [15] produced Al-7075 based hybrid composites reinforced with Al_2O_3 and SiC in same proportions of 1 to 4Wt. % by liquid state process and it is observed that the hardness as well wear resistance has been increased with the escalation in content of reinforcement/ strengthening element compared to Al-7075 base alloy.

Uvaraja and Natarajan [16] carried out the work of fabrication and finding the hardness for SiC (at 0-15Wt. %) and B_4C (at 3Wt. %) reinforced Al-7075 hybrid composites. It is detected that the hardness of composites has been improved with the accumulation of B_4C strengthening element/ reinforcement at 3 Wt. % compared to the base Al-7075 alloy. The improved hardness may be due to harder reinforcements which are the obstacles to the wave of displacement in composite. Further enhancement in hardness is obtained with hybridization effect to the B_4C reinforced composites with SiC reinforcement from 5 to 15Wt. %. The maximum hardness value of 88BHN is observed in hybrid composite of reinforcements SiC (at 15Wt. %) and B_4C (at 3Wt. %).

In the experimentation work done by B. Jayendra *et al.,* [17], the results of mechanical properties have been reported for the hybrid composites of Al-7075 with boron carbide (2, 4 and 6 Wt. %) and graphite (1, 3 and 5 Wt. %) reinforcements at three fixed levels of boron carbide and graphite compositions for total of 9 trials. It is found that the hardness values are improved for the hybrid composites compared to un-reinforced Al-7075 base metal. Hardness value is in increasing manner with the increase in addition of graphite and the peak value of rigidity/hardness is 159 for 95-Al-7075-2-B_4C-3-Gr hybrid composite. The impact strength is also increased with the increase in addition of graphite and the maximum value of 4 joules is observed in the composites filled with 3 and 5 Wt. % of the graphite reinforcement at 2, 4 and 6 Wt. % of the B_4C reinforcement. The UTS value is also in increasing trend with the increasing weight percentage of Graphite due to the good bonding strength provided by boron carbide.

Al-7075 based metal matrix composites reinforced with Si_3N_4 (0, 4, 8 and 12Wt. %) reinforcement are prepared by the researchers S. Arun Kumar *et al.,* [18] through stir casting method. The Vickers micro hardness number of composites has been enhanced/ improved with the increase in addition of silicon nitride filler compared to parent metal alloy and the authors suggested that the further enhancement in hardness can be achieved by heat treatment of samples at above 550^0C so that the porosity in specimens can be reduced for hardness enhancement.

TiC (at 0, 2.5, 5 and 7.5Wt. %) Reinforced Al-7075 based metal matrix composites (MMC) are contrived by K. R. Ramkumar *et al.,* [19] using stir casting method. In their research work they found the hardness (RHN) and bending strength of the composites and they have been improved with the TiC filler addition from 0 to 7.5Wt. % compared to the unfilled Al-7075 composite. The extreme values of hardness (248HRC) and bending strengths (730MPa) were observed in the composites filled with 7.5Wt. % of TiC. The enhancement in mechanical properties may be due to the presence bonding in between matrix and reinforcement, grain refinement, uniform distribution, shape and size of the reinforcement (TiC).

R. Manikandan *et al.,* [20] prepared the hybrid composites reinforced with boron carbide (at interval of 2.5Wt. % up to 10Wt. %) and Cow dung ash (at interval of 2.5Wt. % up to 10Wt. %) reinforcements with Al-7075 as matrix at fixed weight percentage of 90. They reported that the hardness results/values of composites have been increased with the growth in addition of B_4C from0Wt. % to 10Wt. % and at 10Wt. % of Cow dung ash minimum hardness was observed. The maximum value of hardness is 152BHN observed in the composite filled with B_4C at 10Wt. % (Cow dung ash at 0Wt. %). The minimum value of hardness is 102BHN for the composite filled with Cow dung ash at 10Wt. % (B_4C at 0Wt. %) whereas the pure alloy is having the hardness of 110BHN. The 'tensile strength' of the composites also improved with the increase in the addition of boron carbide-B_4C from 0Wt. % to 7.5Wt. % (at 10Wt. % of the B_4C the slight decrease in tensile strength is observed) and at 10Wt. % of Cow dung ash minimum tensile strength is observed. The maximum tensile strength of 288.38MPa observed for the composite 'Al-7075-7.5B_4C-2.5Cow dung ash' and the minimum tensile strength of 184.8MPa is observed for pure Al-7075 alloy. Impact strength of the composites has been decreased with the increase in addition of B_4C from 0Wt. % to 10Wt. % and at 10Wt. % of Cow dung ash the peak value of 'impact strength' was detected compared to other filled composites whereas unfilled Al-7075 alloy has exhibited the maximum impact strength of 3.2 J. The flexural strength of the composites has been augmented with the increase in B_4C from 0Wt. % to 2.5Wt. % (Cow dung ash from 10Wt. % to 7.5Wt. %) further increase in addition of B_4C reinforcement from 5 to 10Wt. % resulted in decrease in flexural strength. The maximum and minimum values of flexural strengths of 358MPa and 300MPa are observed in the composites 'Al-7075-2.5B_4C-7.5Cow dung ash' and 'Al-7075-10B_4C-0Cow dung ash'.

Al-7075 based composites reinforced with TiB_2 at different Wt. % of 0.8, 1.2, 1.6 and 2 are fabricated by stir casting method. It is perceived that with the rise in addition of reinforcement/ strengthening content the mechanical properties like micro hardness, compressive strength and tensile strength were improved compared to Al-7075 base alloy [21]. R. Keshavamurthy *et al.,* [22] also selected the same Al-7075 base alloy to fabricate the composites with TiB_2 reinforcements at 4, 6 and 8 Wt. % and they found the increasing trend of hardness values with the increase in reinforcement addition.

Many researchers have done the work on fabrication and mechanical characterization of Al-7075 based Al_2O_3 reinforced composites having weight percentages of 0%, 2%, 4%, 6%, 8%. They reported that through the increase in addition of Al_2O_3 reinforcements the progress in Tensile strength, hardness, compression strength and impact strengths is observed. The extreme values of mechanical properties are obtained at 8Wt. % of Al_2O_3 reinforcement [23-24]. Al-7075 hybrid composites are prepared with the reinforcement of 5 Wt. % of Graphite along with Al_2O_3 reinforcement with the above compositions ranging from 2% to 8% and all the mechanical properties are increased with reinforcement addition [25].

Balasubramani Subramaniam *et al.,* [26] prepared the hybrid composites reinforced with boron carbide Wt. % of 0, 3, 6, 9 and 12 and coconut shell fly ash (at 3Wt. %) reinforcements with Al-7075 as matrix. They reported that the hardness values of composites are improved with the increase in addition of B_4C.The maximum hardness of 169BHN is obtained for the composite 'Al-7075-12%B_4C-3%CSFA' and the maximum tensile strength of 189MPa for the composite 'Al-7075-9%B_4C-3%CSFA'.

Ashiwani Kumar *et al.,* [27] fabricated the marble dust (at 0, 2, 4 and 6Wt. %) reinforced Al-7075 based composites. In their experimental work they found that with the rise in marble dust addition the hardness/impact strength values were increased and the maximum value of hardness and impact strength are 48HRB and 21.4 KJ/m^2 respectively. Maximum compressive strength of 512MPa is observed for the composite filled with 2Wt. % marble dust and high flexural strength of 528MPa is acquired for the composite reinforced with 6 Wt. % of marble dust.

Mani Sambathkumar *et al.,* [28] have done the fabrication of Al-7075 composites reinforced with red mud an industrial waste at volume fractions of 0, 5, 10, 15 percentages by double stir casting method. It is observed that with the addition or red mud the hardness values are increased and the maximum hardness value of 181.86VHN is observed at 15 Vol. % of red mud. The values of ultimate tensile strength are also increased compared to unfilled composite and the maximum strength of 326MPa is observed for the composite reinforced with red mud at 5 Vol. %.326MPa is observed for the composite reinforced with red mud at 5 Vol. %. S. Rajesh *et al.,* [29] used the fly ash and SiC reinforcements to fabricate the Al-7075 based composites. The reinforcement content ranges from 0 Wt. % to 10 Wt. %. As shown in below Table 1.

Table 1
Composition of the Al-7075 based hybrid composites

S.No.	Wt. % of Al-7075	Wt. % of SiC	Wt. % of fly ash	S. No.	Wt. % of Al-7075	Wt. % of SiC	Wt. % of fly ash
1	100	0	0	6	90	0	10
2	95	5	0	7	90	5	5
3	95	0	5	8	90	2.5	7.5
4	95	2.5	2.5	9	90	7.5	2.5
5	90	10	0	-	-	-	-

It is witnessed that the hardness/ tensile strength results/values of composites were enhanced through the accumulation of fillers when compared with the unfilled composites. The extreme tensile strength and hardness values are 601.9MPa for the composite having '90% Al-7075+7.5% SiC+2.5% fly ash' and 184.67BHN for the composite having '90% Al-7075+5% SiC+5% fly ash' respectively.

In a mechanical performance study of the four Al-7075 hybrid composites reinforced with silicon nitride at (2, 4 and 6 Wt. %), rice husk ash (at 5 Wt. %) and snail shell powder (2, 4 and 6 Wt. %), it is observed that the tensile strength, impact strength and hardness values are improved compared to the unfilled composites. The highest values of hardness, tensile strength and impact strength are 78.6HRB at 91% Al-7075 + 2% $S_{i3}N_4$ + 2% Snail shell powder (SPP) + 5% Rice husk ash (RHA), 154.64MPa at 83% Al-7075 + 6% $S_{i3}N_4$ + 6% Snail shell powder (SPP) + 5% Rice husk ash (RHA) and 12J at 87% Al-7075 + 4 % $S_{i3}N_4$ + 4 % Snail shell powder (SPP) + 5% Rice husk ash (RHA) respectively [30]

The Tensile strength and yield strength of the Al-7075 based composites reinforced with Short basalt fibre at 2, 4 and 6 Wt. %’s were enhanced when compared with the pure Al-7075 alloy. The extreme values of tensile strength and yield strength are 215 MPa and 185MPa respectively for the composites reinforced with 6 Wt. % short basalt fibres [31].

Al-7075 based hybrid composites reinforced with boron carbide at 0, 3, 6 and 9 Wt. % and Titanium diboride at 3 Wt. % are fabricated by stir casting technique. The hardness/ Impact strength/ tensile strength/ compressive strength values are improved with the rise in addition of weight percentage of boron carbide. The extreme values of hardness, Tensile strength and compressive strength are 76Hv; 233MPa and 231MPa respectively are obtained for the Al-7075 based hybrid composite reinforced with 9 Wt. % boron carbide and 3 Wt. % Titanium diboride. But the Impact strength value is maximum at 3% boron carbide and 3% titanium diboride reinforcement and the further addition of boron carbide reinforcements leads do decrease in the values of impact strength [32].

From the literature it is observed that all most all the industrial wastes are used as reinforcements in combination with metal oxide, nitride and carbide reinforcements to the Al-7075 matrix and so many combinations of reinforcements can be added to the Al-7075 to enrich the individualities of the composites. The usage of various agro wastes is reported in a review article in detailed manner written by Bisma Parveez *et al.,* [33]. Ghandva *et al.,* [34] Prepared the Gd added Al-18%Si Alloy for the applications of Automotive and they observed the enhancement in mechanical properties with the addition of Gd. The usage of agro wastes as reinforcement to Al-alloys enhanced the all characteristics compared to Al-base alloy. Along with this the optimization techniques like Taguchi method can be implemented for CNC Turning parameters for cutting Al alloy-based composites to achieve good surface roughness [35].

5. Research Gap

From the literature presented in this article we found some of the gaps presented in the Figure 2 as shown below. Based on the knowledge gap present in the earlier investigations the objectives for future work are framed. The first objective of the work is selection and preparation of filler materials to prepare Al-7075 based metal matrix composites. The selected filler materials are surplus crab shell powder, oyster shell powder, Pearl shell powder and their mixture. The second objective is to fabricate the Al-7075 based composites filled with the above fillers as per the designated compositions by stir casting method. The third objective is mechanical characterization and selection of composites w.r.t their attributes. The fourth objective of the work is estimation of erosion wear behaviour and implementation of optimization techniques.

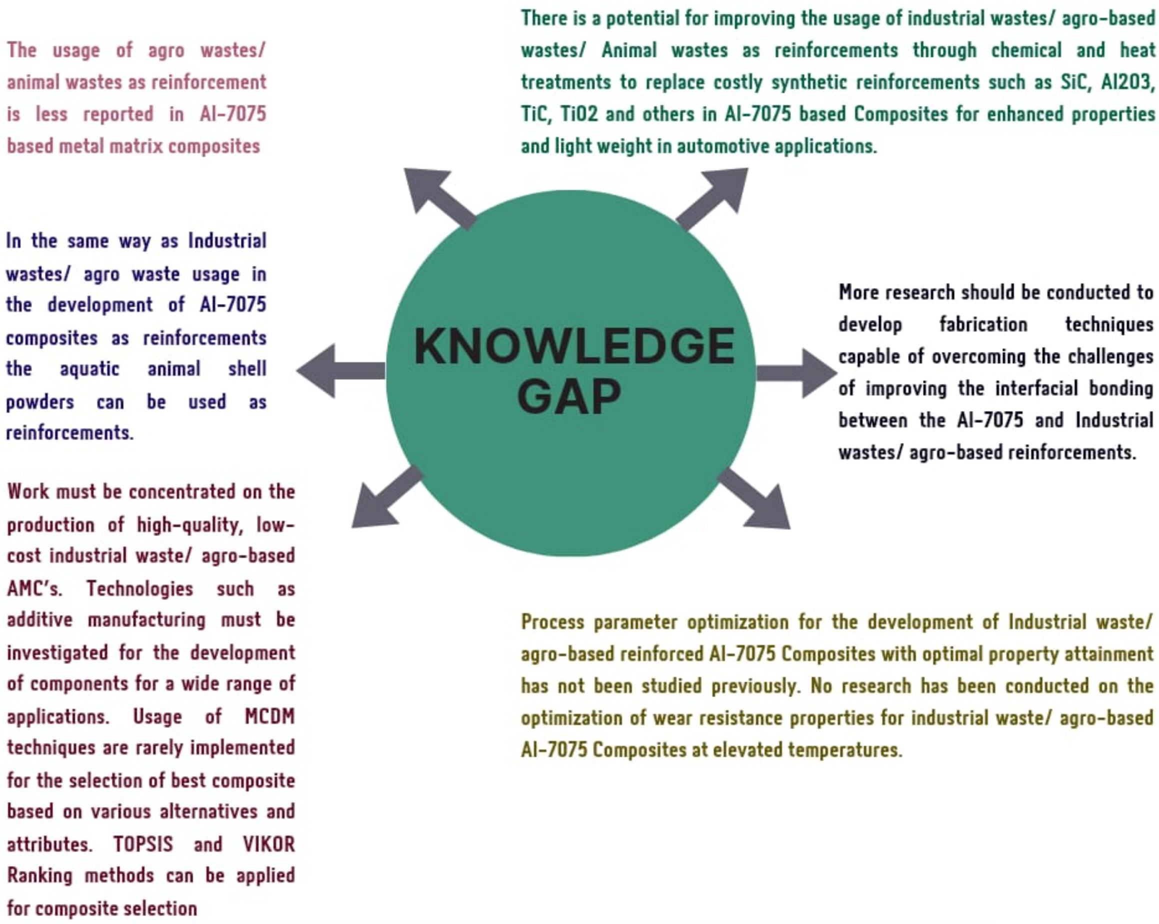

Fig. 2. Knowledge Gap present in the Previous Research Investigations

6. Conclusions

This review has thoroughly discussed various costly ceramic reinforcements and agro-based strengthening elements as reinforcements as well as their effects on mechanical properties along with the manufacturing procedures involved. The key findings are:

i. The addition/accumulation of strengthening elements as reinforcements to the Al-7075 base alloys are enhancing their mechanical properties.
ii. The cost of fabrication of Al based composites can be reduced by the usage of naturally available industrial wastes, agro wastes and aquatic animal shells/bones as reinforcements. The usage of these fillers can reduce the environmental pollution and disposal problems.
iii. The usage of these industrial wastes, agro wastes and aquatic animal shells/ bones as reinforcements in various combinations in Al alloys can reduce the weight of the composites. So, to achieve weight reduction one can use these reinforcements.
iv. These Agro wastes can be used as potential materials for the manufacturing of automotive parts with Al-alloys.

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