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Effect of Magnesium Element on Mechanical and Microstructure Characteristics of M142 Aluminum Alloy

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Abstract

A specific set of criteria for the piston material is established by the piston's actions and the loads acting on it. Pistons should be made of a low-density material if they are to weigh as little as possible. The load capacity of the piston is based on the strength of the material used in its construction in addition to its design shape. Static and dynamic robustness are both required because of the time-varying loads due to the high temperatures and resistance to heat. Aluminum alloy (M142) is ideally used as a piston material because it is a light alloy with high thermal conductivity. However, its power and wear resistance are insufficient in the unalloyed shape. In this research, an attempt has been made to reduce the weight as well as increase the power-to-weight ratio of M142 by adding magnesium (Mg) of 1.5%, 2%, and 2.5%, respectively. The test specimen has been prepared by gravity die casting way and the effect of Mg addition on M142 alloy mechanical properties namely tensile and hardness strength have been evaluated through Brinell and the tensile tester. This research also includes the microstructure analysis of M142 alloy by adding Mg at different amounts. It is confirmed from the research that the tensile and hardness of the material have been improved. The improvement in fatigue and ductility of M142 alloy has been revealed through the microstructure analysis.

Keywords

M142 aluminum alloy, Gravity die casting, Heat treatment, Mechanical and microstructure characteristics

Introduction

Making lightweight automobiles has been prioritized recently in environmental protection initiatives in order to increase fuel efficiency and lessen the harm brought on by the industry's emissions of greenhouse gases [1]. When compared to aluminum and steel, Mg is 33% and 77% lighter, respectively, making it the lightest material. The density of the Mg substance closely resembles that of bone, and it exhibits a notable strength. The Mg alloys and their associated mixtures are extensively employed as conventional implant resources due to their favorable biodegradability and mechanical characteristics [2]. Compared to aluminum alloys, Mg alloys have a lower heat capacity and higher heat dissipation effects, making them excellent options for use as heat dissipation materials [3]. The Mg is typically associated with high-stress corrosion awareness, alloying components, and microstructure. Corrosion *in vitro* environment is three times as fast as that of Mg alloy [4]. The Mg alloys find widespread application in the aviation, automobile, and electronics sectors owing to their favorable attributes such as low density, exceptional damping capability, and elevated specific strength [5].

The Mg alloys that have low density and good functionality have been intensively studied and partially utilized in several industrial sectors due to the rising demands for lightweight structural materials over the past decades [6].

A cylinder in an engine can't function without the piston. Manufacturers are under pressure from intense competition to find and implement the most effective piston material for their engines. Pistons can be made from a variety of materials, from aluminum to steel and iron [7]. Iron is one of the most difficult impurities to remove from aluminum-cast materials, despite the fact that aluminum is one of the most versatile materials utilized in foundry practice [8]. Due to its low weight, ease of manufacturing, attractive appearance, corrosion resistance, and high economic value, aluminum alloys have been used in widespread applications [9, 10]. The majority of piston cylinders, pistons, connecting rods, bearings, etc., in modern automobiles are made of aluminum-based alloys [7]. Heat-resistant aluminum alloys are frequently used in the heat-resistant parts of automobile engines because of their low density, exceptional heat conductivity, very high specific strength at elevated temperatures, and outstanding creep resistance [11]. The physical, mechanical, and tribological properties of piston based on a porcelain grouping are designed, manufactured, and assessed. The results demonstrated that the piston benefited from the addition of porcelain in terms of its physical, mechanical, and wear qualities [12]. Aluminum alloys come in a wide variety, and each has its own set of advantages and disadvantages. M142, LM13, and 3L33 are just a few examples of widely used aluminum alloys in aircraft, automotive, and other manufacturing processes.

Ahmed et al. [13] have addressed the different types of materials used for making the Pistons including cast iron, aluminum alloys, and steel alloys. Because of their low weight and high thermal conductivity, aluminum alloys have largely replaced cast iron as the material of choice for pistons in today's automobiles. Tang et al. [14] used M142 piston aluminum alloy to investigate the impacts of varying silicon, iron, and copper concentrations on the formation of precipitation strengthening phase, type, and transformation. The study conducted by Sun et al. [15] examined the impact of Mg on the microstructure, physical characteristics, and resistance to softening of a copper-chromium alloy. The addition of Mg enhances the material's mechanical characteristics and softening resistance while decreasing its conductivity marginally.

The study conducted by Beroual et al. [16] investigated the impact of heat treatment (HT) on the microstructural properties and mechanical behaviour of Al-Si-Cu and Al-Si-Mg alloys. The authors utilized modest quantities of copper and Mg in order to optimize the hardness of the alloys through the process of solution HT and ageing. The solution treatment period coarsens the microstructure, dissolves intermetallic phases, and homogenizes copper and magnesium distribution in the matrix. Salihu et al. [17] examined how Mg addition affects Al-Cu-Mg alloy mechanical characteristics and microstructure. The alloy's mechanical characteristics improved with Mg addition, peaking at 1.5% Mg. The Mg content also altered microstructure, resulting in smaller and more uniform grains. The study revealed that magnesium can greatly improve Al-Cu-Mg alloys' mechanical characteristics and microstructure. Manjunath et al. [18] examined the way Mg affects Al-Zn-Mg alloy microstructure and mechanical characteristics. Due to little precipitates and microstructure refinement, Mg increased alloy strength and ductility. Because of their increased physical and mechanical qualities, aluminum composites supplemented with Mg nanoparticles are frequently employed for high performance applications. When Mg nanoparticle reinforcement is added to aluminum alloy, impact strength gradually increases [19].

Several types of aluminum alloys are frequently used in the fabrication of pistons. Pistons are now being made using M142 aluminum alloy, which is used for its lightweight and high heat conductivity. The material's mechanical property is inadequate, however, in its unalloyed form. Incorporating alloying elements has proven to be the most popular method of dealing with this problem. A great deal of work has been put into finding a solution to this issue. The major aim of this study was to observe the impact of Mg addition on the microstructure and mechanical properties of the M142 aluminum alloy. This was achieved by introducing different quantities of Mg into the alloy and analyzing the effects.

Materials and Method

Hypereutectic Al-Si alloys are one of the most popular choices for automotive engine parts including cylinders, cylinder heads, cylinder liners, and pistons. A variety of attributes contribute to its desirability, including its corrosion and wear resistance, a relatively minimal coefficient of expansion under heat, and high specific strength. Table 1 displays the chemical contents of M142 aluminum alloys.

Table 1: Chemical composition of M142.

Element	**Si**	**Cu**	**P**	**Mg**	**Fe**	**Na**	**Zn**	**Ni**	**Mn**
Percentage	10	3.14	0.05	1.1	0.3	0.001	0.2	2.5	0.2
Element	**Cr**	**V**	**Ti**	**Ca**	**Zr**	**Sn**	**Pb**	**Al**	
Percentage	0.03	1.15	0.1	0.001	0.1	0.03	0.03	Balance	

After melting and perfect homogeneity, the raw material was hand poured using traditional gravity die casting into a metallic mold. Metals can be made stronger and more durable through a process called HT, which involves heating the metal to a high temperature and then letting it cool to a normal temperature [20, 21]. The yield strength of ductile materials can be improved through an HT process called precipitation hardening. Particle hardening and age hardening are two other names for it. The precipitation hardening method was tested on three samples in this investigation. All the as-cast ingots went through a series of processes including homogenization, hot and cold rolling, and annealing. Following a 30-min solution treatment at 480 °C in an air furnace, the cold-rolled plates were quenched in water [22].

The hardness of a material, often a metal, can be quantified using the Brinell hardness number (BHN). The M142 aluminum alloy specimen is placed on the machine's stage, and the indenter is brought into contact with its surface. The indenter is loaded with a certain force for 20 s by the loading mechanism. The tensile or tension test method used by the material strength testing machine entails applying an ever-increasing load to a test sample until failure occurs. The mechanical characteristics of materials can be ascertained by analyzing the data collected during tensile testing. Standard metallographic procedures, such as grinding, polishing, and etching, were used to produce a small specimen of M142 aluminum alloy for observation of its microstructure under a metallurgical inverted microscope. After preparation, the specimen was placed in a slide or holder and transferred to the microscope's stage. Using a metallurgical inverted microscope with a magnification range of 100x, examine the microstructure of aluminum alloys.

Results and Discussion

The impact of Mg on aluminum alloy hardness depends on alloy composition, manufacturing characteristics, and testing conditions. Three sample pistons are used to observe the BHN. Table 2 details the BHN with phosphorus before and after HT. It is perceived from table 2 that the hardness value of the piston material before HT has increased from 115 to 126 BHN by adding the Mg from 1.5% and 2%, respectively. However, the addition of Mg after 2% can lead to a decrease in the harness value.

The sample resulting from the addition of 1.5%, 2%, and 2.5% Mg to phosphorus post-HT is outlined in table 3. The heat-treated samples are harder than the untreated samples under all conditions. Results indicated that increasing Mg content leads to an increase in hardness up to a certain limit, after which the hardness decreases. After HT, the maximum hardness of the pistons increased from 126 to 131 BHN by increasing the Mg content from 1.5% to 2.5%. The maximum observed hardness of the heat-treated sample is 137 BHN after the addition of 2% Mg. The value of hardness is then decreased by introducing Mg at a 2.5% content.

Figure 1 depicts the tensile strength of the pistons by adding Mg with phosphorus before and after HT. By adding 1.5% Mg to the aluminum alloy M142 with phosphorus, a tensile strength of 203 MPa was observed. Particularly, the tensile strength of the alloys containing 1.5% and 2% Mg increased from 203 MPa to 228 MPa. However, the study also discovered that Mg content above 2.5% decreased tensile strength. Because of the development of brittle intermetallic composites, the mechanical characteristics of the alloy are diminished. Therefore, the optimal quantity of Mg to be added to an aluminum alloy should be determined with care to strike a balance between the increase in strength and the potential loss of other mechanical properties.

Figure 2 depicts the tensile strength of the piston sample by adding Mg without phosphorus before and after HT. The tensile strength increased with up to a 2% increase in Mg content. The maximum tensile strength observed for heat-treated samples with and without phosphorus is 228 and 238 MPa, respectively. In every condition, the heat-treated samples had greater tensile strength than the untreated samples. Odusote et al. [23] examined the influence of Mg content and ageing treatment on the mechanical characteristics of Al-Zn-Mg alloys. The results demonstrated that a rise in Mg content led to greater strength and ductility and that ageing treatment enhanced these properties even further.

Table 2: BHN with phosphorus before and after HT.

S. No.	1.5% of Mg		2% of Mg		2.5 % of Mg	
	Before HT	After HT	Before HT	After HT	Before HT	After HT
1	112	118	124	131	118	129
2	115	120	126	133	124	127
3	118	124	128	132	120	126
Avg	115	121	126	132	121	127

Table 3: BHN without phosphorus before and after HT

S. No.	1.5% of Mg		2% of Mg		2.5 % of Mg	
	Before HT	After HT	Before HT	After HT	Before HT	After HT
1	124	128	130	138	124	129
2	122	124	132	139	126	131
3	121	126	129	135	127	132
Avg	122	126	130	137	126	131

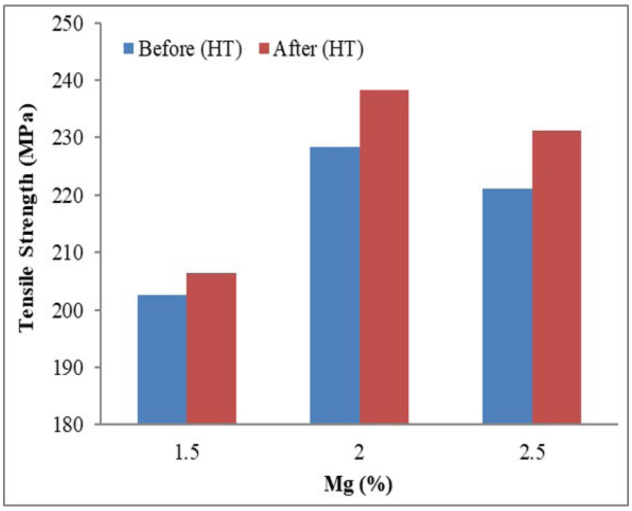

Figure 1: Tensile strength by adding Mg with phosphorus before and after HT.

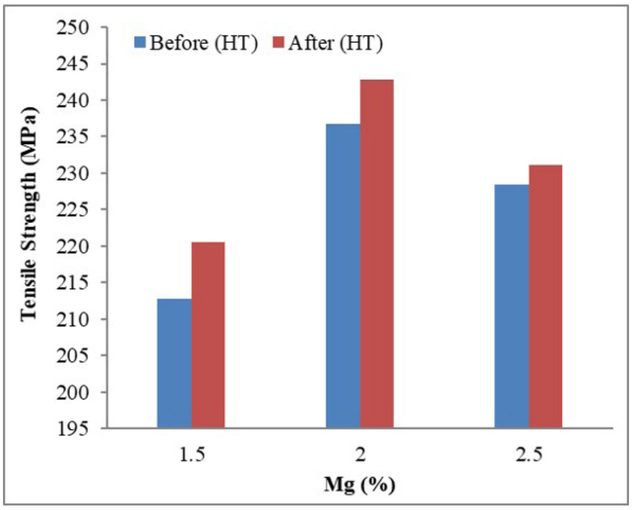

Figure 2: Tensile strength by adding Mg without phosphorus before and after HT.

Figure 3a, 3b, and 3c depict the microstructure of piston samples treated with Mg and phosphorus before HT. The addition of 1.5% Mg to aluminum alloys results in the formation of porosity as seen in figure 3a, as well as losses and alterations to the piston's mechanical properties. Porosity is the presence of voids or holes within a material, which can impair its structure and load-bearing capacity. Porosity can have a considerable negative impact on the mechanical characteristics of a tensile piece, including its tensile strength. The addition of 2% Mg to the aluminum is depicted in figure 3b, and there is no formation of porosity. As a result, mechanical properties such as hardness and tensile strength are imparted to the samples. When the Mg content exceeds 2%, surface oxidation is severe, and the burning rate of Mg increases considerably, resulting in a substantial increase in the body's water absorption. As a result, the ultimate tensile strength and the hardness of the piston are reduced. Figure 3d, 3e, and 3f depict the microstructure of the piston samples made by adding Mg with phosphorus after HT. There is less or no formation of porosity compared to samples before HT, as demonstrated. In addition, the solution treatment has a significant impact on the coarseness of the microstructure, which may result in alterations to the piston's mechanical properties.

Figure 4a, 4b, 4c, 4d, 4e and 4f depicts the microstructure of piston samples produced by the addition of Mg without phosphorous before HT. When 1.5% Mg is introduced to aluminum alloys, the resulting microstructure becomes coarser. In addition, porosity is formed as seen in figure 4a, and there are losses and effects on the piston's mechanical properties. Porosity can cause the material to fail prematurely during tensile testing because stress concentrations can form around the pores, resulting in the initiation and propagation of fractures. This can lead to a reduction in tensile strength and a softening of the material by 2% Mg, no porosity is formed, the size of silicon cuboids is smaller, and the production of dendrites is slower, which could lead to an increase in the mechanical properties of the piston. Increasing the Mg level by more than 2% increases the likelihood of bubble formation and inhibits bubble expansion. Furthermore, the size of the silicon cuboids and dendrites generated is larger, resulting in low strength. However, the tensile and hardness properties of the heat-treated samples improved due to the elimination of pores of both size and number. Microanalysis also showed that the alloy's microstructure had been refined due to the incorporation of Mg at 2% concentration.

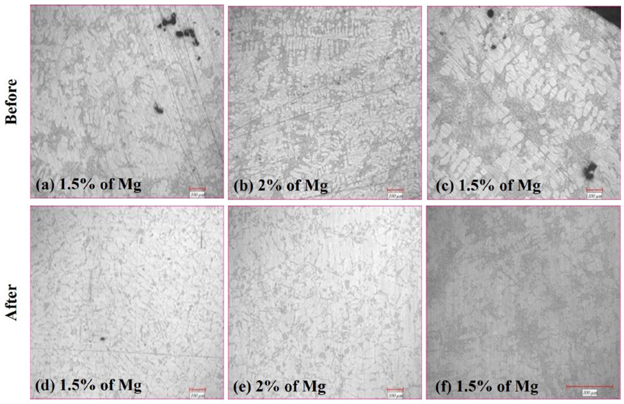

Figure 3: Microstructure of pistons by adding Mg with phosphorus **(a-c)** before and **(d-f)** after HT.

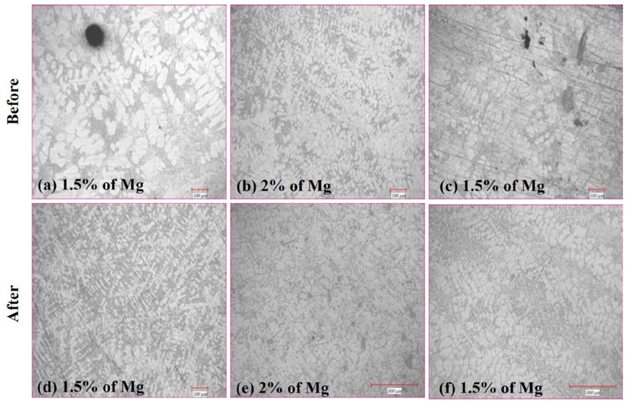

Figure 4: Microstructure of pistons by adding Mg without phosphorus **(a-c)** before and **(d-f)** after HT.

Conclusion

The mechanical characteristics and microstructure of M142 aluminum alloy are considerably improved by the addition of Mg. The study discovered that increasing the Mg percentage of the alloy from 1.5% to 2% increased its hardness and tensile strength. The study discovered that increasing the Mg level by more than 2% reduced the material's tensile strength. Because coarse particles form, the material's mechanical characteristics could decrease. As a result, it's crucial to regulate the Mg content of the alloy precisely. In addition, the tensile strength of heat-treated samples was higher than unheated ones. The results demonstrate that defects produced before HT are eliminated and that the coarseness of the microstructure is greatly impacted by the solution treatment.

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Conflict of Interest

None.

References

1. Ramalingam VV, Ramasamy P, Kovukkal MD, Myilsamy G. 2020. Research and development in magnesium alloys for industrial and biomedical applications: a review. *Met Mater Int* 26: 409-430. https://doi.org/10.1007/s12540-019-00346-8
2. Bommala VK, Krishna MG, Rao CT. 2019. Magnesium matrix composites for biomedical applications: a review. *J Magnes Alloys* 7(1): 72-79. https://doi.org/10.1016/j.jma.2018.11.001
3. Li S, Yang X, Hou J, Du W. 2020. A review on thermal conductivity of magnesium and its alloys. *J Magnes Alloys* 8(1): 78-90. https://doi.org/10.1016/j.jma.2019.08.002
4. Jayasathyakawin S, Ravichandran M, Baskar N, Chairman CA, Balasundaram R. 2020. Mechanical properties and applications of Mag-

nesium alloy–review. *Mater Today Proc* 27: 909-913. https://doi.org/10.1016/j.matpr.2020.01.255

5. Liao H, Kim J, Liu T, Tang A, She J, et al. 2019. Effects of Mn addition on the microstructures, mechanical properties and work-hardening of Mg-1Sn alloy. *Mater Sci Eng A* 754: 778-785. https://doi.org/10.1016/j.msea.2019.02.021
6. Wu G, Wang C, Sun M, Ding W. 2021. Recent developments and applications on high-performance cast magnesium rare-earth alloys. *J Magnes Alloys* 9(1): 1-20. https://doi.org/10.1016/j.jma.2020.06.021
7. Chatterjee S, Chakraborty S. 2022. A multi-attributive ideal-real comparative analysis-based approach for piston material selection. *OPSEARCH* 59(1): 207-228. https://doi.org/10.1007/s12597-021-00536-2
8. Rathinasuriyan C, Bharath A, Sridhar K. 2022. Reducing iron content from aluminium molten bath through filter bag, centrifugal separation and flux refining method. *Mater Today Proc* 62: 1026-1032. https://doi.org/10.1016/j.matpr.2022.04.269
9. Rathinasuriyan C, Karthik K, Sridhar K. 2023. Investigation of degassing on aluminum alloy by rotatory impeller degasser. *Mater Today Proc* 1-6. https://doi.org/10.1016/j.matpr.2023.03.263
10. Georgantzia E, Gkantou M, Kamaris GS. 2021. Aluminium alloys as structural material: a review of research. *Eng Struct* 227: 111372. https://doi.org/10.1016/j.engstruct.2020.111372
11. Sun J, Zeng G, Rao D, Wang Y, Yang Y, et al. 2021. Microstructure and tensile properties of a cast eutectic Al-Si-Cu alloy modified by Zr and V. *Met Mater Int* 27: 5436-5449. https://doi.org/10.1007/s12540-020-00909-0
12. Dev S, Aherwar A, Patnaik A. 2020. Material selection for automotive piston component using entropy-VIKOR method. *Silicon* 12: 155-169. https://doi.org/10.1007/s12633-019-00110-y
13. Ahmed A, Wahab MS, Raus AA, Kamarudin K, Bakhsh Q, et al. 2016. Mechanical properties, material and design of the automobile piston: an ample review. *Indian J Sci Technol* 9(36): 1-7. https://doi.org/10.17485/ijst/2016/v9i36/102155
14. Tang JJ, Liang C, Xu CG. 2022. Effects of alloying elements and temperature on thermodynamic state and microstructure of piston aluminum alloy. *Defect Diffusion Forum* 417: 3-8. https://doi.org/10.4028/p-1421c8
15. Sun Y, Peng L, Huang G, Xie H, Mi X, et al. 2020. Effects of Mg addition on the microstructure and softening resistance of Cu-Cr alloys. *Mater Sci Eng A* 776: 139009. https://doi.org/10.1016/j.msea.2020.139009
16. Beroual S, Boumerzoug Z, Paillard P, Borjon-Piron Y. 2019. Effects of heat treatment and addition of small amounts of Cu and Mg on the microstructure and mechanical properties of Al-Si-Cu and Al-Si-Mg cast alloys. *J Alloys Compd* 784: 1026-1035. https://doi.org/10.1016/j.jallcom.2018.12.365
17. Salihu SA, Isah A, Evarastics P. 2012. Influence of magnesium addition on mechanical properties and microstructure of Al-Cu-Mg alloy. *IOSR J Pharm Biol Sci* 4: 15-20.
18. Manjunath GK, Bhat KU, Kumar GP. 2022. Effect of zinc content on the microstructure and mechanical properties of Al-Zn-Mg alloy. *Mater Today Proc* 54: 240-244. https://doi.org/10.1016/j.matpr.2021.08.301
19. Girish KB, Jayakumar A, Janardhana HD, Girish BS. 2017. Wear and impact characterization of A356.1 aluminium alloy reinforced with magnesium nano particle. *Int J Eng Res Technol* 6: 962-966.
20. Rathinasuriyan C, Karthik K, Udhayaraj S, Bishwakarma S. 2023. Investigation of induction hardening on heat-treated EN8 steel by alternately timed quenching process. *Mater Today Proc* 1-6. https://doi.org/10.1016/j.matpr.2023.03.216
21. Chandran R, Udhayaraj S, Eazhil KM. 2022. Effect of the heat-treatment process on the mechanical and microstructure properties of EN8 steel. *Int J Surf Eng Interdiscip Mater Sci* 10(1): 1-12. https://doi.org/10.4018/IJSEIMS.313628
22. Pan Y, Zhang D, Liu H, Zhuang L, Zhang J. 2021. Precipitation hardening and intergranular corrosion behavior of novel Al-Mg-Zn(-Cu) alloys. *J Alloys Compd* 853: 157199. https://doi.org/10.1016/j.jallcom.2020.157199
23. Odusote JK, Adeleke AA, Muraina SA, Ikubanni PP, Omiogbemi IMB. 2021. Magnesium inclusion effect on Al-Zn-Cu alloys: a study on microstructure and mechanical properties. *Mater Today Proc* 46: 5914-5921. https://doi.org/10.1016/j.matpr.2021.03.539