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Powder-Assisted Thermal Treatment of Forged Al 6063 Alloy: Procedure and Preliminary Hardness Observations

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Abstract **- Aluminium alloys are widely used in engineering applications because of their low density, good corrosion resistance and favourable mechanical properties. However, their relatively soft surface limits their use in sliding or abrasive environments. In this work, forged Al 6063 specimens were subjected to powder-assisted thermal treatment in two stages. In the first stage, aluminium and molybdenum powders were coated on the specimen surface, wrapped in aluminium foil and heated in a furnace at 550 degrees Celsius. In the second stage, aluminium, titanium and molybdenum powders were applied, the specimen was packed using aluminium foil and copper wire, and it was heated at a reported 600 degrees Celsius for approximately 8 to 9 hours. Surface hardness of the plain, untreated specimen and of the specimen treated with aluminium, titanium and molybdenum powders was evaluated by the Brinell method, using a 2.5 mm ball, a 62.5 kgf load and ten indentations per specimen. The recorded readings for the two specimens are numerically identical and give a mean of 275.49 BHN with a standard deviation of 10.42 BHN, which is far higher than values usually reported for Al 6063. The readings therefore could not be verified and do not demonstrate any hardness improvement.**

Keywords - Al 6063 alloy; heat treatment; hardness; Brinell hardness number; powder-assisted treatment; diffusion; molybdenum; titanium; aluminium alloy.

I. INTRODUCTION

Aluminium alloys have earned a firm place in modern engineering, especially in the automotive, aerospace, marine and structural sectors, because they combine low density with good strength, excellent corrosion resistance and easy fabrication. In vehicles and aircraft, every kilogram saved translates into better fuel efficiency and lower emissions, which is why aluminium has steadily replaced heavier ferrous materials in many components. Among these alloys, Al 6063 is a familiar and dependable choice. It belongs to the Al–Mg–Si family of the 6xxx series and gets its strength from fine Mg_2Si precipitates that block the movement of dislocations inside the aluminium matrix. It forms easily, extrudes well, welds without much trouble, offers a smooth surface finish and responds nicely to anodising, which is why it is so often found in window and door frames, architectural sections, pipes, heat sinks and many lightweight structural parts. Yet for all its convenience, Al 6063 is only a medium-strength alloy, and its surface is relatively soft. When it is asked to work under harsh conditions such as sliding contact, abrasion, fretting or repeated surface loading, the surface tends to deform plastically, wear through adhesion, become scored and gradually lose material. This limits its use in places where a component must stay light but also survive constant rubbing and surface stress, so finding a way to make the surface tougher without spoiling the alloy's useful bulk properties is a worthwhile engineering goal.

Since wear, fatigue and corrosion damage nearly always begin at the surface, it makes more sense to strengthen just that outer layer than to change the composition of the entire component, which would be costly and could compromise the very properties that make aluminium attractive. Many surface engineering methods exist for this purpose, including anodising, thermal spraying, vapour deposition, laser alloying, friction stir processing and various diffusion-based treatments, each with its own trade-offs in cost, equipment needs, coating thickness and compatibility with aluminium. Powder-assisted heat treatment stands out as a simple and economical option among the diffusion-based routes. In this approach, fine metallic powders are placed on or around the component, which is then held in a furnace at a controlled temperature for a set time. At that temperature, atoms from the powder migrate into the surface, and the substrate interacts with the powder in return, changing the chemistry and microstructure of the near-surface region. Depending on the elements involved, this can bring about solid solution strengthening, the formation of hard intermetallic compounds and a finer surface microstructure. Molybdenum and titanium are of interest here, as both are high-melting-point metals that are expected to raise hardness, wear resistance and thermal stability. Titanium can react with aluminium to form hard Al–Ti intermetallics such as Al_3Ti, while molybdenum can contribute through solid solution effects and the formation of Al–Mo compounds. Aluminium powder is used alongside them as a carrier that helps the powder layer bond with the substrate. Because only a thin surface layer is altered, the lightweight, ductile and corrosion-resistant core of the alloy remains largely intact, which is the key advantage of this method over through-thickness alloying.

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Against this background, the present work sets out to examine whether the surface properties of forged Al 6063 alloy can be modified using aluminium, molybdenum and titanium powders under controlled furnace heating conditions. Forging was chosen as the processing route because it refines the grain structure, closes internal porosity and improves the overall soundness of the material, giving a more uniform base for the surface treatment. To judge how well the treatment works, Brinell hardness measurements were carried out on two specimens: a plain, untreated aluminium specimen that serves as the reference, and a specimen treated with aluminium, titanium and molybdenum powders. Comparing the two was intended to show whether the powder-assisted treatment changes the surface hardness. As reported in Sections V and VI, however, the recorded readings for the two specimens are identical and could not be verified, so this paper is presented as a description of the procedure with preliminary observations rather than as evidence of treatment effectiveness.

II. LITERATURE REVIEW

The background to this study is drawn from the following eight research works.

Aydi et al. [1] studied the mechanical properties and microstructure of AA6063 aluminum alloy after extrusion and T5 heat treatment. Their research showed that artificial aging significantly improved strength and hardness because of the precipitation hardening effect caused by Mg_2Si particles. The study also concluded that heat treatment parameters strongly influence the final mechanical properties and microstructure of AA6063 alloy.

Esezobor and Adeosun [2] investigated the improvement in strength of 6063 aluminum alloy using solution heat treatment. The authors reported that tensile strength increased with increase in solution treatment duration and appropriate aging conditions. Their work demonstrated that solution heat treatment and precipitation hardening are effective techniques for improving the mechanical behavior of AA6063 alloys.

Adeosun et al. [3] examined the effect of heat treatment on forged and rolled AA6063 aluminum alloy. The study showed that heat treatment processes such as homogenization, solution treatment, quenching, and aging improved both strength and ductility. The improvement was mainly attributed to the formation of fine Mg_2Si precipitates and refined microstructure within the aluminum matrix.

Sopha and Nansaarng [4] investigated the influence of forging temperature on the properties of Al6063 alloy. Their results indicated that forging temperature significantly affects grain size and hardness. Lower forging temperatures produced finer grains and higher hardness values, while higher temperatures reduced hardness due to grain growth.

Dashti et al. [5] studied multi-directional forging of AA6063 alloy and reported considerable improvement in hardness and strength after severe plastic deformation and heat treatment. Grain refinement and increased dislocation density were identified as the primary reasons for enhanced mechanical properties.

John et al. [6] reviewed various surface modification techniques including laser cladding and diffusion-based coating methods for improving hardness, wear resistance, and corrosion resistance of engineering materials. The authors emphasized that surface engineering techniques improve service life by modifying only the surface layer without affecting bulk properties.

Edoziuno et al. [7] investigated reinforcement effects in AA6063-based composites and observed improvements in mechanical properties and wear resistance due to grain refinement and uniform particle distribution. Their work highlighted the importance of reinforcement particles in enhancing hardness and structural performance.

Cui et al. [8] studied the microstructure and properties of 6063-T6 aluminum alloy under thermal processing conditions. Their research concluded that thermal cycles strongly influence microstructure evolution, hardness, and mechanical properties of the alloy. The study also emphasized the role of controlled heating conditions in improving material performance.

III. METHODOLOGY

The forged Al 6063 samples were cleaned thoroughly before the experiment. Any oil, grease, dust or loose surface oxide left on the metal can act as a barrier between the powders and the substrate, preventing atoms from diffusing across the interface and leading to patchy, uneven treatment. The surfaces were therefore degreased and cleaned so that the powders could make direct contact with fresh aluminium. Clean, dry surfaces also help ensure that the two treatments can be compared fairly, since both specimens begin from the same surface condition. The initial temper, specimen dimensions, cleaning method and surface roughness were not recorded. The overall procedure is summarised in Fig. 1.

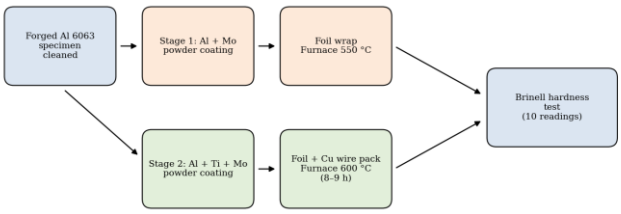


Fig. 1. Flow of the experimental procedure for the two treatment stages and the hardness test.

In the first heat treatment, aluminium and molybdenum powders were applied uniformly over the surface of the sample so that the entire face to be treated was covered with a layer of consistent thickness. Uniform coverage is important because thin or bare patches would receive less alloying material and would harden less than the rest of the surface. After coating, the specimen was wrapped completely in aluminium foil, which holds the powder layer in place, keeps it pressed against the surface, limits direct exposure of the powders to the furnace atmosphere and reduces powder loss during handling and heating. The wrapped specimen was then heated in a furnace at 550 °C, a temperature below the melting range of Al 6063, so the substrate remained solid, while being high enough for solid-state diffusion between the powders and the aluminium surface to be possible.

In the second heat treatment, a combination of aluminium, titanium and molybdenum powders was coated onto the sample surface (Fig. 2). Titanium was introduced in addition to molybdenum with the aim of promoting the formation of hard

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Al–Ti phases and obtaining a greater hardening effect than the first treatment; the formation of such phases was not confirmed.



Fig. 2. Sample with aluminium, molybdenum and titanium powder coating.

The coated specimen was wrapped tightly in aluminium foil and secured with copper wire (Fig. 3), which tightens the foil around the specimen and keeps the powders firmly pressed against the surface throughout heating. This matters because diffusion depends on close atomic contact, and any gap between the powder and the substrate would reduce the amount of material that can diffuse in. Furnace heating (Fig. 4) was reported at 600 °C for approximately 8 to 9 hours; this temperature is close to the melting range of Al 6063. Compared with the first stage, the higher temperature and longer holding time were intended to give the atoms more energy and more time to move, so that diffusion could proceed deeper into the surface layer; the actual diffusion depth was not measured.



Fig. 3. Sample with aluminium foil and copper wire wrapped.



Fig. 4. Sample placed for heat treatment.

At elevated temperature, atoms of the alloying elements are expected to diffuse from the powder layer into the surface of the aluminium substrate, driven by the concentration difference between the two. Titanium and molybdenum can react with aluminium to form hard intermetallic phases, for example Al_3Ti and Mo-bearing aluminides. In addition, dissolved atoms distort the aluminium lattice and hinder dislocation motion (solid-solution strengthening), while fine dispersed particles obstruct dislocation movement further (dispersion strengthening). Together, these effects are expected to raise the surface hardness and improve resistance to wear and surface deformation. The tight foil-and-wire packing maintains close contact between the powders and the substrate, which promotes diffusion and reduces the chance of unreacted gaps. Because diffusion depth increases with both temperature and time, the higher temperature and longer soaking period of the second stage are expected to produce a deeper and more effective modified layer than the first stage. Since the modification is expected to be confined to the near-surface region, the lightweight and corrosion-resistant bulk of the Al 6063 alloy should be largely preserved, although the thermal cycle itself may alter the bulk alloy (Section VI). The parameters of the two stages are compared in Table I.

TABLE I. HEAT TREATMENT PARAMETERS

Parameter	Stage 1	Stage 2
Powders applied	Al + Mo	Al + Ti + Mo
Containment	Aluminium foil	Aluminium foil + copper wire
Furnace temperature	550 °C	600 °C
Soaking time	Approximately 6 to 7 hours	Approximately 8 to 9 hours

IV. MATERIALS AND EQUIPMENT

The materials and equipment used in the investigation, together with their purpose, are listed in Table II.

TABLE II. MATERIALS AND EQUIPMENT USED

Material / equipment	Purpose
Forged Al 6063 sample	Base material
Aluminium powder	Powder-pack constituent (carrier)
Molybdenum powder	Intended surface modification (not verified)
Titanium powder	Intended alloying addition (phase formation not verified)

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Material / equipment	Purpose
Aluminium foil	Wrapping and containment of the powder layer
Copper wire	Tight packing of the specimen
Furnace	Heat treatment (reported 550 °C and 600 °C)
Brinell hardness tester	Surface hardness measurement (2.5 mm ball, 62.5 kgf)

V. HARDNESS TESTING

A. Principle of the Brinell Test

In the Brinell test a hardened spherical indenter of diameter D (mm) is pressed into the specimen surface under a fixed load P (kgf). After the load is removed, the diameter d (mm) of the permanent circular impression is measured, and the Brinell Hardness Number (BHN) is calculated from the load divided by the curved surface area of the impression:

$$BHN = \frac{2P}{\pi D\left(D-\sqrt{D^2-d^2}\right)} \quad (1)$$

The tabulated values were recomputed from (1) and agree with the values obtained from the recorded diameters. This checks the arithmetic only; it does not validate the measured diameters, the load or the measuring scale. The specimen after testing is shown in Fig. 5.

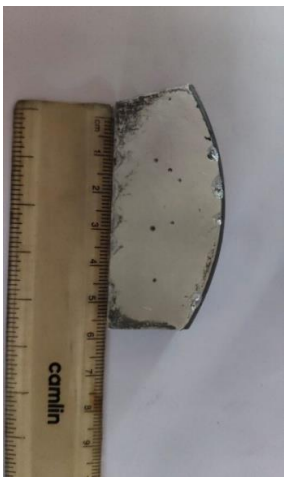


Fig. 5. Sample after hardness test.

B. Test Parameters

TABLE III. BRINELL TEST PARAMETERS

Parameter	Value
Test method	Brinell hardness (BHN)
Ball diameter, D	2.5 mm
Applied load, P	62.5 kgf ($P/D^2 = 10$)
Number of readings per specimen	10
Specimens tested	Plain aluminium; Al + Ti + Mo treated

C. Measured Results

Table IV lists the recorded indentation diameters and the calculated BHN for each reading on the plain aluminium specimen and on the Al + Ti + Mo treated specimen. The two sets of values are identical (see Section VI).

TABLE IV. RECORDED INDENTATION DIAMETERS AND BRINELL HARDNESS NUMBERS

Reading	Indentation dia. d (mm)	Load (kgf)	Plain Al (BHN)	Al + Ti + Mo (BHN)	Difference (BHN)
1	0.525	62.5	285.50	285.50	0.00
2	0.530	62.5	280.07	280.07	0.00
3	0.519	62.5	292.21	292.21	0.00
4	0.531	62.5	279.01	279.01	0.00
5	0.535	62.5	274.80	274.80	0.00
6	0.546	62.5	263.71	263.71	0.00
7	0.533	62.5	276.89	276.89	0.00
8	0.535	62.5	274.80	274.80	0.00
9	0.555	62.5	255.12	255.12	0.00
10	0.537	62.5	272.74	272.74	0.00

VI. RESULTS AND DISCUSSION

Ten indentations were made on each specimen. The indentation diameters ranged from 0.519 mm to 0.555 mm, giving Brinell hardness values between 255.12 and 292.21 BHN, with a mean of 275.49 BHN and a standard deviation of 10.42 BHN (coefficient of variation 3.78 %). The scatter between readings is moderate. Reading 3 (d = 0.519 mm) was the hardest point and reading 9 (d = 0.555 mm) the softest. The data files for the plain aluminium specimen and for the Al + Ti + Mo treated specimen contain the same ten indentation diameters, and therefore give identical BHN values, means and standard deviations. On this evidence, the recorded data show no difference between the two specimens (0.0 % change). The figures in this report should be regarded as the recorded data rather than as confirmed material properties, although the calculation procedure itself has been checked and is correct for the recorded values.

The second stage used a higher temperature (600 °C) and a long soak (8 to 9 hours), which should favour diffusion of titanium and molybdenum into the aluminium surface, and the foil-and-wire packing keeps the powder layer in intimate contact with the substrate. Prolonged exposure at 600 °C, however, is close to the solidus range of Al 6063 and can also affect the bulk alloy. Mg_2Si precipitates may dissolve or coarsen and grains may grow, so the base-metal temper may soften unless the part is subsequently solution-treated, quenched and aged, as discussed in the reviewed literature. The final hardness is therefore the net result of surface strengthening and any bulk softening, and the cooling route needs to be controlled and recorded. Since hardness is generally correlated with resistance to abrasive and adhesive wear, a verified increase in surface hardness would be expected to improve wear resistance, but this should be confirmed experimentally.

VII. FUTURE SCOPE

- Repeat the Brinell tests on independent plain and treated specimens, recording the raw impression measurements, dwell time and indenter details.
- Add Vickers or Knoop microhardness traverses across the cross-section to measure the hardness profile and effective case depth.
- Characterise the surface layer by optical microscopy, SEM–EDS and XRD to confirm Ti/Mo diffusion and intermetallic formation.

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- Carry out pin-on-disc or abrasive wear tests and compare wear rate and friction coefficient with untreated Al 6063.
- Study the effect of temperature, soaking time, powder composition and a post-treatment solution/ageing cycle.

VIII. CONCLUSION

The study investigated powder-assisted heat treatment of forged Al 6063 alloy using aluminium, molybdenum and titanium powders at reported temperatures of 550 °C and 600 °C. The foil-and-wire packing technique is simple and low-cost to implement, but neither surface diffusion nor intermetallic formation was verified, so the feasibility of the treatment remains to be demonstrated.

Brinell hardness tests (2.5 mm ball, 62.5 kgf, ten readings) gave a mean of 275.49 BHN with a standard deviation of 10.42 BHN for both the plain and the Al + Ti + Mo treated data sets. Because the two sets are identical and the absolute values are far above those normally reported for Al 6063, a hardness improvement cannot be confirmed from the present data. The measurements should be repeated and verified, and supported by microhardness, microstructural and wear testing, before conclusions on the effectiveness of the treatment are drawn. No hardness improvement or wear benefit has been demonstrated in this work.

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