

Synergistic effect of hot rolling and T6 Heat Treatment on the Mechanical Behaviour of Gravity Die Cast A356 Alloy

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Abstract

Secondary processing techniques offer a practical approach for improving the performance of cast aluminium alloys without introducing reinforcement particles. This study investigated the individual and synergistic effects of hot rolling and T6 heat treatment on the mechanical behaviour of gravity die-cast A356 alloy. The alloy was produced by gravity die casting and subsequently subjected to four processing conditions: as-cast, hot rolled, T6 treated, and hot rolled followed by T6 treatment. Mechanical characterisation was performed through tensile and hardness testing, while optical microscopy was used to examine the corresponding microstructural evolution. The results showed that hot rolling significantly improved ductility through microstructural refinement and defect closure, whereas T6 heat treatment substantially enhanced strength and hardness through precipitation hardening. The combined hot rolling and T6 treatment produced the best overall mechanical performance, increasing the ultimate tensile strength from approximately 118 MPa in the as-cast condition to about 248 MPa while simultaneously improving elongation from approximately 7% to 11%. The combined treatment also exhibited the highest hardness, longest time to fracture (273.599 s), and greatest total deformation (5.471 mm), indicating superior resistance to crack initiation and propagation. Optical microstructural observations confirmed progressive refinement and improved structural homogeneity following secondary processing. The study demonstrates that the sequential application of hot rolling and T6 heat treatment generates a synergistic strengthening effect, providing an industrially scalable strategy for enhancing the performance of gravity die cast A356 alloy for lightweight structural and automotive applications.

Keywords: A356 Alloy; Gravity Die Casting; Hot Rolling; T6 Heat Treatment; Severe Plastic Deformation Techniques

1. Introduction

Aluminium is one of the most widely used engineering materials in the manufacturing, automotive, aeronautic and process industries due to its lightweight and high strength-to-weight ratio. Its ductility, electrical conductivity, and castability are some of the critical features that make it attractive to many industries (Gök et al., 2024; Vani & Chak, 2018). However, it is limited by low strength, high wear rate and low hardness when compared to other structural materials like steel. To improve the properties of aluminium alloys, several strategies have been investigated by researchers, including reinforcing with secondary materials, design and optimisation of the production process, and the use of secondary treatment (Kumar et al., 2020; Sharma et al., 2021).

There are many studies on the use of secondary materials to improve the mechanical properties of aluminium alloys. Abolusoro *et al.* (2024) produced composites from recycled aluminium cans reinforced with RHA at 0-20% through stir casting. Tensile strength rose to a peak at 10 wt.% (121.6 MPa) before dropping at higher contents. Hardness increased with RHA fraction while density fell to 2.46 g/cm³ at 20 wt.%. Micrographs showed generally uniform dispersion at moderate loadings, but some agglomeration and porosity at high ash levels. Poornesh *et al.* (2024) developed

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functionally graded Al-Si alloys reinforced with CSA using centrifugal casting and mixture-method optimisation. The optimised compositions (7.5-9.5 wt.% CSA) and process parameters produced tensile strengths up to 197 MPa. The study showed that CSA, when milled and graded and combined with process optimisation parameters, such as mixing speed and temperature, can deliver very large tensile strengths in Al-Si matrices. : Lal *et al.* (2019) characterised A356 composites reinforced with boron-carbide (B₄C) particulates fabricated by liquid metallurgy. The study reported systematic increases in hardness and tensile properties with increasing B₄C fraction, and highlighted that particle sizes affect homogeneity and strength.

Despite these gains in material properties, certain challenges still persist that can impede industrial adoption of composite technology. These challenges include, agglomeration of reinforcement materials and understanding the interfacial chemistry between reinforcement particles and the parent matrix. These are crucial issues that must be considered for scaling as most composites studies are still at the laboratory stage. The production of such composites may require new tooling, adjustment to production lines to accommodate the procedures adopted in research. This makes it important to critically analyse other measures to improve the properties of aluminium alloys without necessarily adding secondary materials. Secondary treatments of aluminium alloys, such as heat treatment and severe plastic deformation techniques, are strategies that could improve their mechanical properties. Heat treatment is a thermal processing route used to alter the microstructure of aluminium alloys and their composites after casting. The goal is to enhance strength, ductility, and wear resistance by precisely controlling heat treatment parameters, including temperature, soaking time, heating rate, and cooling medium (Ajide *et al.*, 2016).

Several studies have been conducted to examine the impact of heat treatment procedures such as T6 heat treatment, and severe plastic deformation techniques such as hot rolling on the properties of aluminium alloys and their composites. Chandrashekar *et al.* (2024) subjected the composites to a solutionising treatment at 540°C for 8 hours, quenching in water, and artificial ageing at 155°C for 6 hours. The T6-treated composites exhibited remarkable improvements in UTS and hardness, attributed to uniform precipitation hardening and enhanced particle-matrix bonding. Compared to the as-cast condition, wear resistance increased significantly, making the composites more reliable for automotive applications. The dual reinforcement size, combined with T6, promoted refined microstructures and enhanced mechanical properties. In Li *et al.* (2019), in-situ ZrB₂/AA6016 AMCs were fabricated by a molten salt reaction system and subsequently processed through large strain hot rolling to achieve 60% reduction. This was followed by friction stir process at 1200 rpm and 60 mm/min. Microstructural characterisation by SEM, EBSD and TEM showed exceptional refinement, with grain size reduced from 189.7 µm to 3.8 µm and ZrB₂ particles fragmented to 20 nm with uniform dispersion. Mechanical properties improved significantly, as tensile strength increased from 140.1 MPa to 163.4 MPa, elongation from 46.3% to 78.9% and hardness from 43.4 HV to 59.8 HV, indicating a nearly 100% improvement in strength and ductility.

It is against this backdrop that this study was designed to examine the effect of secondary processing techniques such as T6 heat treatment and hot rolling on a selected aluminium alloy (A356) itself. The study also investigated the synergistic effect of combining these two secondary treatment processes on the mechanical properties and microstructural evolution of the alloy. The aim is to present an easily scalable approach for strengthening aluminium alloys that can aid industrial adoption.

2. Methodology

2.1. Casting procedure

The elemental composition of the A356 alloy used for this study is as presented in Table 1, containing 91.80 wt.% Al, 7.36 wt.% Si and 0.37 wt.% Mg, which qualifies it as an A356 alloy. An electric-powered casting furnace was first preheated from room temperature to 750 °C before introducing 1 kg of the metal. The metal was kept in the furnace for about 2 hours until it was completely transformed into its molten state, then 0.2 wt.% of degasser was added to remove dissolved gases and inclusions from the melt. Thereafter, the temperature was maintained at 750 °C for another 10 minutes, before pouring into a gravity die casting mould that was preheated at 350 °C (Orhadahwe *et al.*, 2026). The cast metal was allowed to cool in the mould under room temperature conditions. The mould was then disassembled to eject the cast.

Table 1 Elemental composition of the A356 alloy used

Element	Si	Fe	Mg	Ti	Mn	Zn	Cu	Cr	Others	Al
wt. %	7.36	0.24	0.37	0.06	0.01	0.02	0.01	0.01	0.12	91.80

2.2. Procedure for T6 heat treatment

The cast was shared into three parts for sample preparation to represent as-cast, hot-rolled, and T6-treated conditions. T6 treatment was conducted by subjecting the metal to solutionising heat treatment, which involves heating the metal at 540 °C for 6 hours followed by quenching in Water. Thereafter, the metal is subjected to artificial ageing treatment by heating the metal in an oven set at 160 °C for 6 hours, followed by air cooling (Arsha et al., 2024). The samples prepared from the T6 treatment were designated as 'T6', while those from the as-cast condition were designated as 'As-cast'.

2.3. Hot rolling procedure

A sample measuring 120 mm by 40 mm by 12 mm was prepared from the third part for hot rolling. Hot rolling was performed by combining thermal treatment with severe plastic deformation. The metal sample was introduced into a heat treatment furnace preheated to 500 °C and maintained for 10 mins per rolling cycle (Luo et al., 2024). Thereafter, the heated metal block was passed through the jaw of a laboratory-scale rolling machine with two roller drums operating at a rolling speed of 3 rpm. Each rolling cycle involved 3 passes to ensure uniform deformation across the length of the sample. The rolling sequence was continued until a target thickness reduction of 75% was achieved. The rolled sample was divided into two parts; the first part was tested in the as-rolled condition (designated as rolled), while the second part was subjected to T6-treatment to remove residual stresses due to rolling (designated as rolling + T6).

2.4. Mechanical testing

The samples were characterised by tensile, hardness and microstructural examinations. The tensile test sample was prepared in accordance with ASTM E8 standards for flat samples. The tensile test was conducted using a TestTek -50, servo-controlled ultimate tensile testing machine. The hardness test was conducted on samples measuring 20 mm by 20 mm by 3 mm. The hardness test samples were polished by dry and wet polishing using emery cloth from coarse to fine grits (80 to 2500 grit). This was followed by machine polishing using a graphite spray of 0.5 micron until a mirror finish was obtained. Brinell hardness was done in accordance with ASTM E10-23 using a Tinius Olsen machine with a maximum test force of 62.5 kgf and an indenter with a diameter of 2.5 mm. The microhardness was investigated using a Banbros Vickers hardness machine. The sample was subjected to a 200 gf for a dwell time of 10 s, and the Vickers hardness values were computed electronically.

2.5. Microstructural examination

The microstructures of the samples were examined with the aid of an optical microscope (LEICA DM 2500 M). The samples measuring 20 mm by 20 mm by 3 mm were polished using the same procedure for polishing the hardness test samples. After cloth polishing, the samples were etched by dipping them in Keller's reagent for 2-3 seconds, then rinsed with distilled water and dried. The etched samples were examined under the microscope, and optical micrographs were captured.

3. Results and Discussion

3.1. Tensile behaviour

The engineering stress–strain curves of the as-cast, hot-rolled, T6-treated, and hot-rolled + T6-treated A356 alloy are presented in Fig. 1, while the corresponding ultimate tensile strength (UTS), elongation, and tensile parameters derived from the tensile test are presented in Fig. 2 and Table 2. The results demonstrate that the different secondary treatment routes altered the deformation behaviour of the alloy in distinct ways. The as-cast specimen exhibited the lowest tensile strength with moderate ductility, whereas the combined hot rolling and T6 treatment produced the highest ultimate tensile strength and elongation, indicating that the sequential application of thermomechanical deformation and precipitation hardening generated a synergistic enhancement of the alloy's mechanical performance.

The as-cast alloy exhibited a relatively low tensile strength of approximately 118 MPa, which is characteristic of gravity die-cast Al–Si alloys containing coarse α -Al dendrites, interconnected eutectic silicon particles, casting porosity and

other solidification-induced defects that act as preferential sites for crack initiation during tensile loading. These microstructural features restrict the alloy's ability to sustain high applied stresses and promote early fracture. Similar observations have been reported for cast A356 alloys, where the coarse dendritic morphology and heterogeneous eutectic silicon network were identified as the primary factors limiting tensile performance before secondary processing (Harada et al., 2011; Kim et al., 2021).

Hot rolling produced only a marginal increase in ultimate tensile strength (123 MPa) but substantially improved elongation compared with the as-cast alloy. This behaviour suggests that thermomechanical deformation primarily enhanced the alloy's plastic deformation capability rather than its intrinsic resistance to deformation. During hot rolling, deformation at elevated temperature promotes pore closure, reduces casting-related defects and elongates the dendritic structure along the rolling direction while simultaneously increasing dislocation density. The elevated temperature also facilitates dynamic recovery, preventing excessive work hardening that would otherwise reduce ductility. Consequently, the rolled alloy can accommodate greater plastic strain before fracture, explaining the marked increase in elongation despite the relatively small improvement in tensile strength. Similar deformation behaviour has been reported during hot rolling of A356 alloys and other Al–Si systems, where defect closure and microstructural refinement improved ductility while only moderately increasing strength in the absence of subsequent ageing treatment (Dash & Chen, 2023; Gravier et al., 2022; G. Li et al., 2021).

In contrast, the T6-treated specimen exhibited a remarkable increase in ultimate tensile strength, reaching 223 MPa, representing an increase of almost 89% over the as-cast condition, although with lower elongation than the rolled sample. This substantial improvement is attributed to precipitation hardening, which remains the principal strengthening mechanism in Al–Si–Mg casting alloys. During solution treatment, magnesium- and silicon-rich phases dissolve into the aluminium matrix, forming a supersaturated solid solution after quenching. Artificial ageing subsequently promotes the precipitation of fine β'' -Mg₂Si strengthening precipitates that effectively impede dislocation movement. The increased resistance to dislocation motion requires higher applied stresses for plastic deformation, thereby significantly increasing tensile strength. However, the same strengthening mechanism also restricts dislocation mobility during deformation, explaining the reduction in ductility compared with the rolled specimen. Similar responses have been consistently reported for heat-treated A356 alloys and Al–Si–Mg systems subjected to T6 ageing (Azimi et al., 2021; Chandrashekar et al., 2024).

The greatest improvement in tensile behaviour was achieved after combining hot rolling with T6 heat treatment. The rolled + T6 specimen attained the highest ultimate tensile strength of approximately 248 MPa while simultaneously exhibiting the highest elongation of about 11%, outperforming all other processing conditions. This demonstrates that the two processing routes do not merely contribute independently to strengthening but interact synergistically to optimise the mechanical response of the alloy. Hot rolling introduces a refined deformation substructure with increased dislocation density and fragmented eutectic silicon particles, while simultaneously reducing porosity and improving matrix continuity. These deformation-induced defects subsequently serve as favourable nucleation sites for precipitation during artificial ageing, leading to a finer and more homogeneous distribution of strengthening precipitates throughout the aluminium matrix. The resulting microstructure combines effective precipitation strengthening with enhanced deformation compatibility, enabling simultaneous improvement in both strength and ductility. Similar synergistic interactions between thermomechanical processing and precipitation hardening have been reported for aluminium alloys subjected to sequential deformation and ageing treatments, where deformation accelerates precipitation kinetics and improves precipitate distribution while maintaining favourable ductility (Arbo et al., 2018; Bignon et al., 2023; Boczkal et al., 2024).

The tensile parameters presented in Table 2 provide further evidence of the beneficial effect of combining both processing routes. Although the T6-treated specimen exhibited a maximum failure load comparable to that of the rolled + T6 specimen, it fractured after a considerably shorter testing duration and experienced much lower total deformation before failure. Conversely, the rolled + T6 specimen required the longest time to fracture (273.599 s) and recorded the greatest total deformation (5.471 mm), indicating superior resistance to crack initiation and propagation under tensile loading. This behaviour suggests that the combined treatment enhanced not only the strength of the alloy but also its fracture tolerance and energy absorption capability. Such characteristics are particularly desirable for structural automotive components that experience fluctuating mechanical loads during service, where resistance to crack propagation is equally as important as ultimate tensile strength.

The tensile behaviour demonstrates that secondary processing provides an effective and industrially scalable approach for improving the mechanical performance of gravity die-cast A356 alloy without introducing external reinforcement phases. Hot rolling primarily enhances ductility through defect closure and microstructural refinement, whereas T6 heat treatment contributes significant strengthening through precipitation hardening. Their sequential application

exploits the complementary advantages of both processes, resulting in simultaneous improvements in tensile strength, ductility, deformation capacity and fracture resistance. This synergy highlights the considerable potential of thermomechanical processing as a practical strategy for producing high-performance cast aluminium alloys while avoiding many of the manufacturing complexities associated with particle-reinforced metal matrix composites.

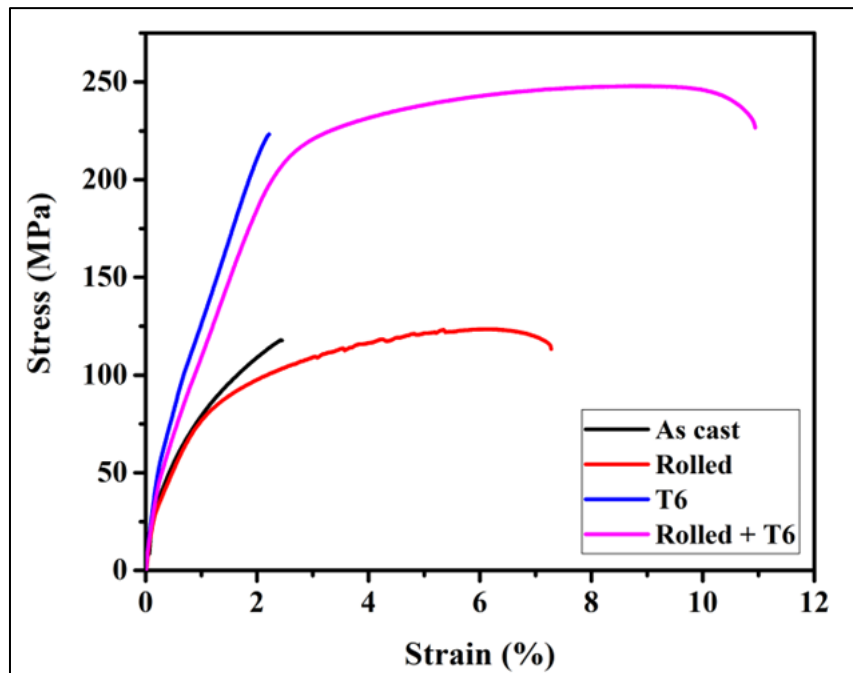


Figure 1 Tensile stress-strain curve

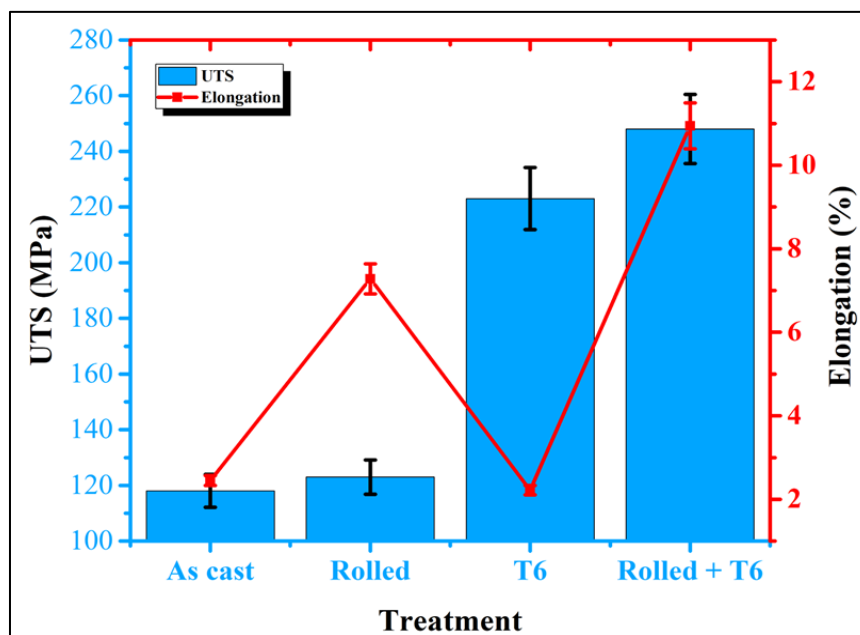


Figure 2 Ultimate tensile strength (UTS) and Elongation of samples

Table 2 Other mechanical responses derived from the stress-strain curve

Treatment	Time to fail (s)	Max load at failure (KN)	Total deformation (mm)
As cast	58.399	2.118	1.224
Rolled	180.799	2.168	3.633
T6	55.399	4.018	1.109
Rolled + T6	273.599	4.078	5.471

3.2. Hardness behaviour

The bulk Brinell hardness and Vickers microhardness of the as-cast, hot-rolled, T6-treated and hot-rolled + T6-treated A356 alloy are presented in Fig. 3(a) and Fig. 3(b), respectively. The results reveal that both hardness measurements followed a similar trend, with progressive improvements after hot rolling and T6 heat treatment, while the combined hot rolling and T6 treatment produced the highest hardness values. This behaviour demonstrates that secondary processing substantially increased the resistance of the alloy to both localised plastic deformation and bulk indentation, confirming that thermomechanical processing effectively strengthened the gravity die cast A356 alloy without introducing reinforcement particles.

The as-cast alloy exhibited the lowest hardness because its microstructure was dominated by coarse α -aluminium dendrites, relatively large eutectic silicon particles and casting defects that offered limited resistance to indentation. During indentation, plastic deformation is accommodated primarily through dislocation movement within the relatively soft aluminium matrix, resulting in lower hardness values. Previous studies have shown that the coarse dendritic morphology commonly associated with as-cast A356 alloys contributes to reduced hardness because dislocations encounter fewer effective obstacles during deformation (Harada et al., 2011; Kim et al., 2021; Chen et al., 2023). Furthermore, the presence of casting porosity and heterogeneous eutectic silicon distribution promotes localized deformation beneath the indenter, thereby lowering the measured hardness.

Hot rolling produced a noticeable increase in both bulk hardness and microhardness relative to the as-cast alloy. The improvement can be attributed to the combined effects of deformation-induced grain refinement, increased dislocation density and pore closure during rolling. Plastic deformation at elevated temperature fragments the dendritic network and compresses casting defects, thereby increasing the effective load-bearing area of the material. Simultaneously, deformation introduces numerous dislocations that interact with one another to impede further dislocation motion during indentation. Although dynamic recovery occurs during hot rolling, a considerable proportion of these deformation structures are retained, contributing to the observed hardness increase. Similar improvements following hot rolling have been reported for A356 alloys and other Al–Si systems, where thermomechanical deformation produced finer microstructures, reduced casting defects and enhanced hardness through strain hardening and microstructural refinement (Li et al., 2021; Luo et al., 2024; Kumar et al., 2021; Dash & Chen, 2023).

The T6-treated alloy exhibited a more pronounced increase in hardness than the hot-rolled specimen, indicating that precipitation hardening provided a stronger strengthening contribution than deformation alone. During solution treatment, alloying elements such as magnesium and silicon dissolve into the aluminium matrix to form a supersaturated solid solution after quenching. Artificial ageing subsequently promotes the precipitation of fine coherent β'' -Mg₂Si precipitates, which effectively obstruct dislocation movement and increase the stress required for localized plastic deformation. Consequently, both Brinell and Vickers hardness values increase significantly. The increase in hardness observed after T6 treatment is therefore primarily associated with precipitation strengthening rather than grain refinement. Similar hardness responses have been consistently reported for heat-treated Al–Si–Mg alloys, where the formation of finely dispersed strengthening precipitates substantially improved indentation resistance (Azimi et al., 2021; Chandrashekar et al., 2024; Lee et al., 2024; Kaygısız & Kayan, 2022).

The highest hardness values were obtained after combining hot rolling with T6 heat treatment, confirming that the sequential processing route generated a synergistic strengthening effect. The enhanced hardness is attributed to the simultaneous operation of multiple strengthening mechanisms. Hot rolling refines the deformation substructure, fragments eutectic silicon particles and increases dislocation density, while subsequent T6 treatment promotes a more homogeneous precipitation of strengthening Mg₂Si particles throughout the refined matrix (Orhadahwe et al., 2026). The deformation-induced dislocations introduced during rolling also serve as preferential nucleation sites for precipitates during artificial ageing, accelerating precipitation kinetics and improving precipitate distribution. The interaction of grain refinement, strain hardening, precipitation strengthening and defect elimination therefore produces

a microstructure that offers maximum resistance to localised plastic deformation. Similar synergistic strengthening mechanisms have been reported in thermomechanically processed aluminium alloys, where prior deformation significantly enhances precipitation efficiency during ageing and results in superior hardness compared with either process applied independently (Bignon et al., 2023; Boczkal et al., 2024).

Although both hardness measurements followed similar trends, slight differences between the Brinell and Vickers responses are expected because the two techniques probe different material volumes. Brinell hardness reflects the resistance of the bulk microstructure to deformation over a relatively large indentation area and is therefore influenced by the overall distribution of phases, grain structure and casting defects (Hassasi et al., 2020). In contrast, Vickers microhardness measures deformation over a much smaller region, making it more sensitive to localized microstructural features such as precipitate density, eutectic silicon morphology and local grain refinement (Chidambaram et al., 2019). The close agreement between the trends obtained from both hardness techniques indicates that the strengthening mechanisms induced by hot rolling and T6 treatment were uniformly distributed throughout the alloy rather than being confined to isolated regions. Such consistency also suggests that the processing routes produced a relatively homogeneous microstructure, which is desirable for engineering components subjected to complex service loading.

The hardness results corroborate the tensile behaviour discussed in Section 3.1. While hot rolling primarily strengthened the alloy through deformation-induced microstructural refinement and defect closure, T6 treatment contributed substantial precipitation strengthening. Their sequential application enabled these mechanisms to operate simultaneously, producing the highest hardness values and demonstrating that secondary processing can significantly improve the mechanical performance of gravity die-cast A356 alloy without the need for ceramic or carbonaceous reinforcements. This finding further supports the potential application of combined thermomechanical processing as a practical and scalable route for manufacturing high-strength aluminium castings for automotive and structural engineering applications.

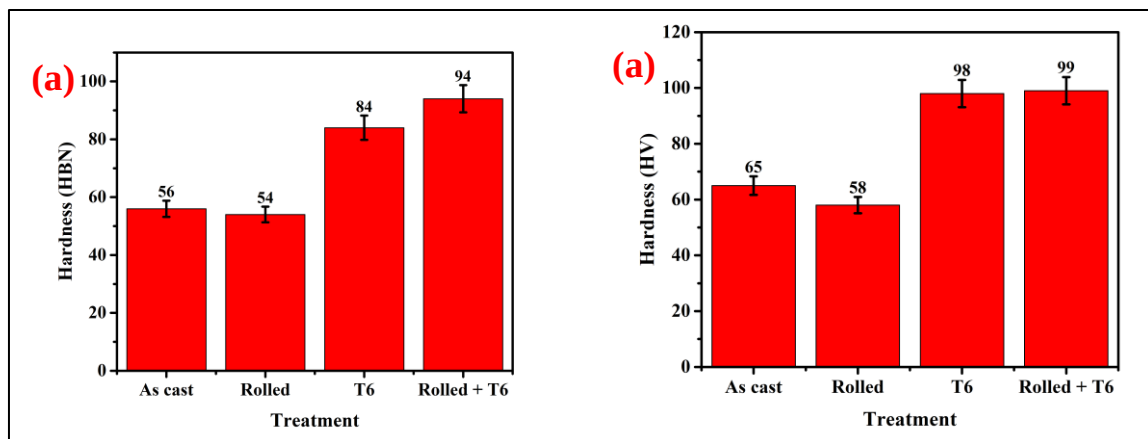


Figure 3 Hardness response of samples (a) Bulk hardness (b) micro-hardness

3.3. Microstructural evolution

The optical micrographs of the as-cast, hot-rolled, T6-treated and hot rolled + T6-treated A356 alloy are presented in Fig. 4. The microstructures reveal progressive changes in grain morphology and phase distribution following the different secondary processing routes, providing clear evidence of the mechanisms responsible for the improvements observed in the tensile and hardness properties. The microstructural evolution demonstrates that hot rolling and T6 heat treatment modified the internal structure of the alloy through different but complementary mechanisms, ultimately producing the refined microstructure associated with the highest mechanical performance.

The as-cast alloy (Fig. 4a) exhibited the characteristic microstructure of hypoeutectic A356 alloy, consisting of coarse primary α -aluminium dendrites surrounded by eutectic silicon distributed within the interdendritic regions (Harada et al., 2011). The dendritic network appeared relatively coarse with non-uniform eutectic regions, which are typical features of conventionally solidified Al–Si casting alloys. Such coarse microstructures generally promote localized stress concentration during mechanical loading because the irregular eutectic silicon particles and casting defects serve as preferential sites for crack initiation and propagation. The observed microstructure explains the relatively low tensile strength and hardness measured in the as-cast condition. Similar microstructural characteristics have been reported

for gravity die cast A356 alloys before secondary processing, where coarse dendritic structures were identified as the primary factor limiting mechanical performance (Kayani et al., 2024).

Following hot rolling (Fig. 4b), the microstructure became noticeably more compact, with deformation-induced alignment of the microstructural constituents along the rolling direction. The rolling operation imposed severe plastic deformation while the elevated processing temperature facilitated dynamic recovery, resulting in the collapse of casting porosity and improved matrix continuity. The applied compressive stresses also fragmented portions of the eutectic silicon network and disrupted the coarse dendritic morphology inherited from casting. These microstructural modifications reduced the number of internal stress concentrators and promoted a more homogeneous distribution of strain during tensile loading. The improved structural continuity is consistent with the higher elongation and moderate increase in hardness observed after rolling. Similar microstructural refinement following hot rolling has been widely reported in A356 and other Al–Si alloys, where pore closure and dendrite fragmentation contributed significantly to improved ductility and mechanical reliability (Dash & Chen, 2023; Luo et al., 2024).

The T6-treated specimen (Fig. 4c) exhibited a more homogeneous microstructure than the as-cast alloy, reflecting the influence of solution treatment and artificial ageing. During solutionising, partial dissolution of nonequilibrium eutectic constituents occurs together with the gradual spheroidisation and coarsening of eutectic silicon particles. Subsequent artificial ageing promotes precipitation strengthening through the formation of finely dispersed Mg_2Si precipitates within the aluminium matrix. Although these nanoscale precipitates cannot be resolved using optical microscopy, the observed improvement in microstructural uniformity, together with the significant increase in tensile strength and hardness, strongly suggests that precipitation hardening became the dominant strengthening mechanism after T6 treatment. Comparable microstructural evolution has been reported for heat-treated Al–Si–Mg alloys, where silicon spheroidisation combined with precipitation hardening substantially enhanced mechanical performance (Hennum et al., 2024; Lee et al., 2024).

The most refined microstructure was obtained after combining hot rolling with T6 heat treatment (Fig. 4d). Compared with the other processing conditions, the microstructure appeared more homogeneous with fewer observable casting defects and a more uniformly distributed second-phase network. The prior deformation introduced during hot rolling likely provided numerous dislocation structures that subsequently acted as preferential nucleation sites during artificial ageing, promoting a finer and more uniform precipitation response throughout the matrix. Simultaneously, the reduction of casting defects achieved during rolling improved matrix integrity, while T6 treatment stabilised the refined microstructure through precipitation hardening. The resulting combination of grain refinement, defect elimination and precipitation strengthening produced a microstructure capable of simultaneously resisting crack initiation and sustaining plastic deformation, thereby explaining the superior tensile strength, hardness and elongation observed in the rolled + T6 specimen. Similar synergistic interactions between thermomechanical processing and ageing have been reported in aluminium alloys, where prior deformation enhances precipitation kinetics and produces superior processing–microstructure–property relationships compared with either treatment applied independently (Bignon et al., 2023).

The progressive microstructural refinement observed across the four processing conditions demonstrates that the improvements in mechanical behaviour were not produced by a single strengthening mechanism but rather by the cumulative effects of thermomechanical processing and heat treatment. Hot rolling primarily modified the cast structure through deformation, pore closure and refinement of the dendritic network, whereas T6 treatment optimised the alloy through precipitation hardening and microstructural homogenisation. Their sequential application therefore generated a favourable processing–microstructure–property relationship in which the refined microstructure provided improved resistance to deformation while maintaining sufficient ductility for structural applications. This finding demonstrates that substantial enhancement of gravity die-cast A356 alloy can be achieved through carefully controlled secondary processing alone, providing an attractive alternative to reinforcement-based strengthening strategies for engineering applications.

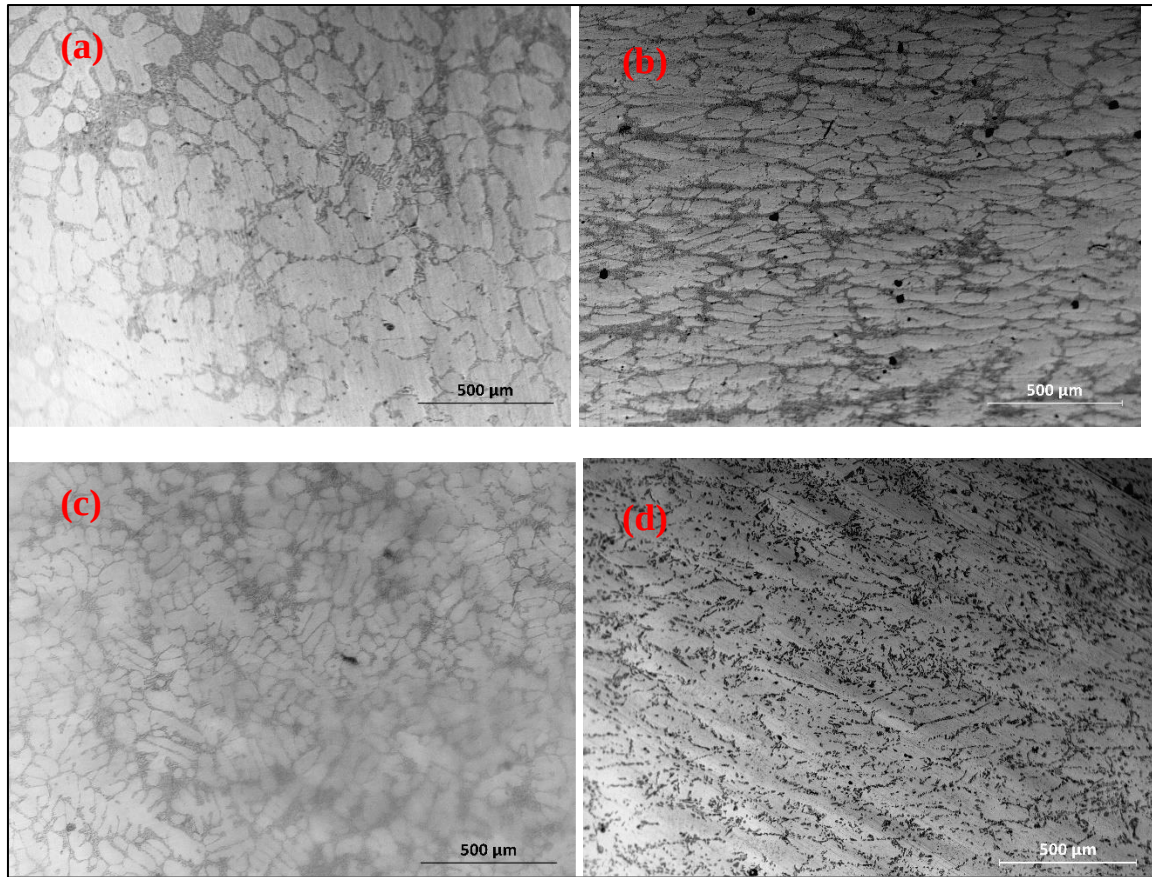


Figure 4 Optical Micrograph (a) As cast (b) hot rolled (c) T6 treated (d) Rolling + T6 treatment

4. Conclusion

This study investigated the individual and synergistic effects of hot rolling and T6 heat treatment on the mechanical behaviour and microstructural evolution of gravity die-cast A356 alloy. The results demonstrated that the two secondary processing routes influenced the alloy through different strengthening mechanisms. Hot rolling primarily enhanced ductility by reducing casting defects, refining the cast microstructure and improving matrix continuity, whereas T6 heat treatment significantly increased tensile strength and hardness through precipitation hardening. The sequential application of hot rolling followed by T6 heat treatment produced the best overall mechanical performance, yielding the highest ultimate tensile strength, hardness, elongation, time to fracture and deformation capacity. The optical microstructural observations supported the mechanical test results by revealing progressive microstructural refinement and improved structural homogeneity after secondary processing.

More importantly, the study established that the simultaneous application of hot rolling and T6 heat treatment generated a genuine synergistic strengthening effect rather than the simple additive contribution of two independent processing routes. The refined deformation substructure produced during hot rolling enhanced the effectiveness of subsequent precipitation hardening, resulting in simultaneous improvements in strength and ductility that neither treatment achieved independently. This demonstrates that substantial enhancement of gravity die-cast A356 alloy can be achieved through carefully controlled secondary processing without introducing external reinforcement particles.

From an engineering perspective, the findings highlight an industrially scalable approach for improving the performance of cast aluminium alloys while avoiding the processing complexities associated with particle-reinforced metal matrix composites. The proposed thermomechanical processing route therefore offers considerable potential for the manufacture of lightweight, high-performance aluminium components for automotive and other structural engineering applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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