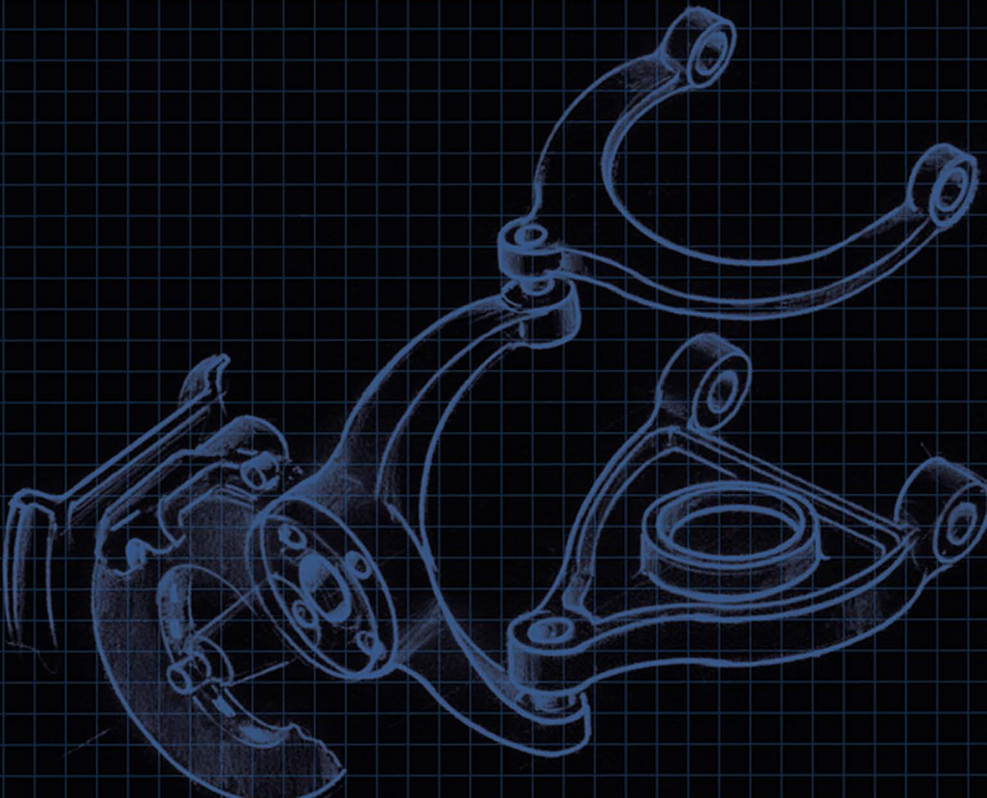
ALUMINUM CASTINGS ENGINEERING GUIDE

Jagan Nath



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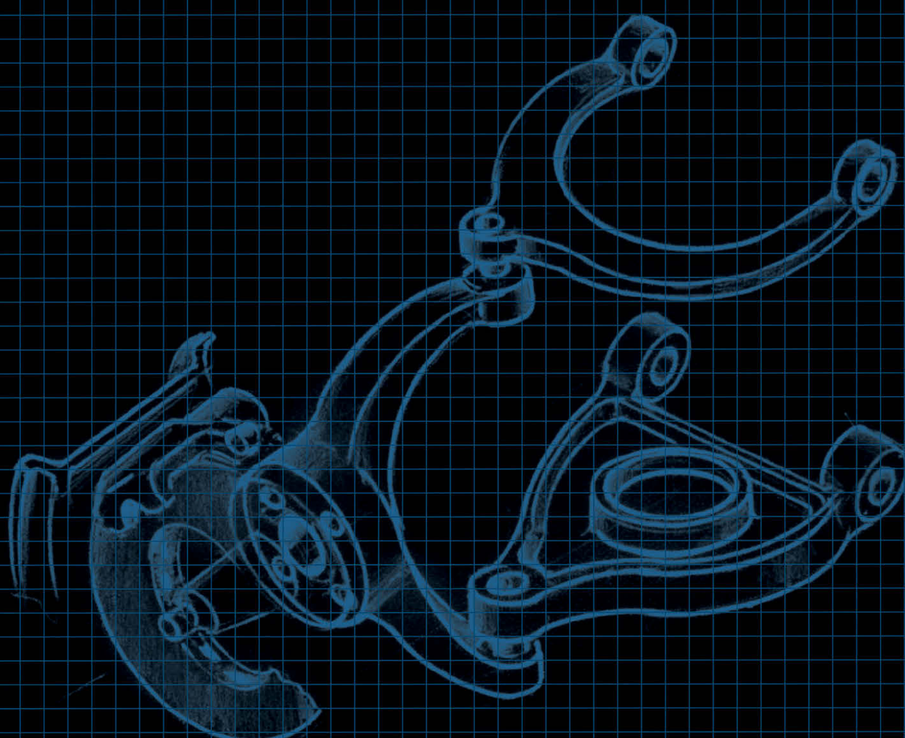

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To my wife Geetha

Contents

Preface

Casting is one of the most economical manufacturing processes for providing shape to components of machinery, and it covers a wide range of industries. It has evolved over many centuries, from being depicted in artwork dating back to 4000 B.C., to being used in the most demanding structural applications of today, such as the aerospace and automotive industries. Aluminum has proven to be the material of choice, for strength, durability, styling and recycling, for various applications. It has successfully replaced iron and steel over the years, bringing economic and environmental benefits to many industries.

The *Aluminum Castings Engineering Guide* is a compilation of years of engineering and practical experience in the manufacture of millions of aluminum castings of the highest integrity in the industry.

This book offers a structured approach to linking the two basic needs of functionality and manufacturability. Product designers can benefit from the knowledge of casting processes and materials, and casting process engineers can benefit from a rational approach to developing configurations that are manufacturable, economical, and competitive.

Extensive examples and practical guidelines illustrate the principles and proven practices. The tables present concise information that can be used for ready reference.

The book presents:

- Simultaneous engineering for the most optimal and cost-competitive product configurations
- Overview of casting processes including green sand, air set or no-bake molding, vacuum molding, evaporative foam casting, gravity permanent molding, counter pressure casting, squeeze casting, investment casting, rapid prototype casting, cast–forge hybrid, and semi-solid metal process
- Best process and alloy selection guidelines for products
- Die casting engineering and gating options
- Detailed descriptions and illustrations of gravity permanent mold casting—tooling, feeding, and gating engineering
- Detailed descriptions and illustrations of low-pressure permanent mold casting—pioneering concepts for engineering castings of the highest quality in the industry
- Typical product specifications, and
- Product launches for successful manufacturing

The application of finite element analysis and 3D printing in the design of castings and prototype manufacturing is also discussed.

Product design engineers, casting manufacturing engineers, casting buyers, foundry personnel in the aluminum casting field, and students specializing in casting technology will find this guide very useful and practical.

Jagan Nath

About the Author

As a mechanical, metallurgical, and materials engineer by profession, Jagan Nath has contributed to the advancement of the casting industry. He became the vice president of advanced engineering of Amcast Automotive, a division of Amcast Industrial Corporation, in Michigan, and later, the vice president of engineering of General Aluminum Manufacturing Company in Michigan.

The author has contributed significantly to automotive vehicle mass reduction through many conversions to aluminum from iron and steel. He pioneered the successful application of the low-pressure process to safety-critical suspension components.

He has guided several teams of engineers in product-process development and problem solving of iron, steel, and aluminum castings in a variety of industries for over four decades. He has authored many papers that have been published and presented at ASM, AFS, and SAE conferences and in many other forums.

The author's unique and pioneering ideas implemented in gravity and low-pressure permanent molding earned him the "Technology Leadership Award" from Amcast Industrial Corporation and the "Merton Flemings Award" for innovation, from Advanced Casting Research Center in Massachusetts.

CHAPTER 1

Aluminum Casting Applications

1.1 Introduction

Casting is one of the most economical manufacturing processes for providing shape to components of machinery and is used in a wide range of industries. It has evolved over many centuries, beginning with artwork dating back to 4000 B.C., and today it is used for the most demanding structural applications in the aerospace and automotive industries. Aluminum has proven to be the material of choice, for its strength, durability, styling and recyclability, for various applications. It has successfully replaced iron and steel over the years, bringing economic and environmental benefits to many industries.

Aluminum applications have grown steadily over a decade and continue to lead other materials in automotive, household appliances, garden and agricultural powertrain markets. The automotive industry has been a dominant driver for the conversion of many components to aluminum.

Casting component producers have been challenged to offer attractive prices, squeezing profit margins. To maintain a competitive edge, designs must be optimized for functionality and manufacturability. Optimum component design, appropriate choice of the alloy, and selection of the best manufacturing process are the critical cost factors.

Ideally, the optimum designs are achieved if the design for functionality is developed concurrently with the design for manufacturability, keeping the secondary process costs to a minimum. Knowledge of basic tooling design and the machining processes positions the company to be competitive. Very few component manufacturers have co-located the resources for both product design and process simulations. Companies who have facilities for machining, testing, and even subassembly are at a significant advantage.

Great strides have been made in applying finite element analysis (FEA) to structural product design. Finite element analysis and other methods have also been effectively applied to simulation of casting solidification and fluid flow. Recent advances in solidification analysis have been instrumental in successfully converting many safety-critical automotive castings from iron and steel castings to aluminum castings that meet all of the demanding quality requirements.

This book is a structured approach to linking the two basic needs of functionality and manufacturability. Product designers can benefit from knowledge of casting processes and materials, and casting process engineers can benefit from a rational approach to developing configurations that are manufacturable, economical, and competitive.

1.2 Aluminum Casting Advantages and Applications

Many ductile iron and stamped steel components have been successfully converted to aluminum alloys, and these products have been performing without any issues over many years. Aluminum's major advantages and some of its familiar applications are listed in Table 1.1.

1.3 Aluminum Casting Limitations

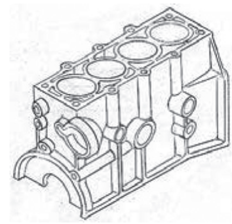
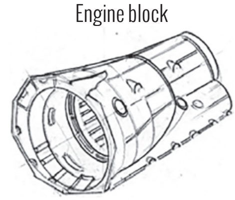
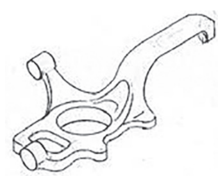
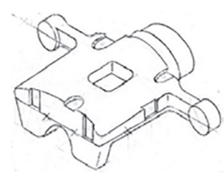
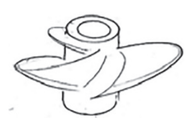
It is essential to recognize the limitations of aluminum when developing applications, especially when converting from ductile iron and steel stampings. Table 1.2 summarizes the limitations of aluminum for castings applications.

1.4 Aluminum Castings Market Growth

The advantages offered by aluminum make it the preferred choice of material for several applications. Significant growth of up to 6% is expected worldwide in the next four years, in sectors such as:

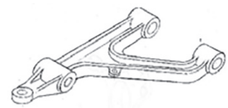
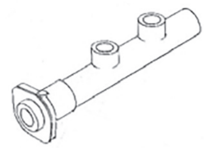
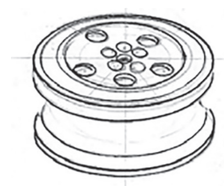
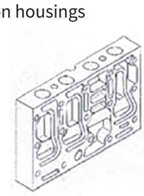
- Automotive
- Household appliances (washers, dryers, dishwashers, mowers, cookware)
- Refrigeration and air conditioning (food industry, dairy products)
- Railroad
- Transportation (freight trucks, commuter trains)
- Commercial and military aircraft structures (door panels, stowing and seat brackets, speed brakes)
- Aerospace, aero engine parts, avionics
- Military vehicles and weapon systems
- Medical and imaging equipment

Table 1.1 Aluminum advantages and applications

Advantages	Details	Typical applications
Mass reduction	30–35% over ductile iron or stamped steel. Advantages include: • Improved fuel economy of vehicles • Reduced emissions • Superior ride handling	Engine blocks Automotive wheels Cylinder heads Crankcases Steering knuckles Control arms  Engine block
Excellent castability	Design freedom to combine sections and form complex shapes. Advantages include: • Cost advantage through reduced number of parts • Weight reduction through thin wall capability • Potential for high casting-quality	 Transmission housing
Heat treat capability	Ability to enhance engineering properties. Advantages include: • Meeting varied product needs • Improving dimensional stability	Structural components such as steering knuckles and control arms  Steering knuckle
Pressure tightness	• Ability to function with high-pressure fluids	Brake master cylinders Brake calipers ABS housings  Brake caliper
Corrosion resistance	Advantages include: • Minimum property deterioration with time • Reduced maintenance costs • Improved aesthetic appeal • Anodizing and clear coating can enhance corrosion resistance.	Marine engine propeller Aluminum wheels  Marine propeller

(*continued*)

Table 1.1 (continued)

Advantages	Details	Typical applications
Damping capacity	Superior to stamped steel components	Lower control arms  Front lower control arm
Excellent machinability	• Superior machinability compared to steel • Machinability improved by increased magnesium content	Brake master cylinders Valve bodies ABS housings  Master cylinder
Aesthetic appeal	Bright finish due to fine microstructures caused by high cooling rates of metal molds, and attractive wheel face styles	Automotive wheels Rear lower control arms (seen at back of vehicle) Brake calipers (seen through wheel spokes)  Automotive wheel
Smooth or textured surfaces	• Die castings provide surface finish options and chrome plating ability	Motorcycle parts and outboard marine parts
	• Good reflectivity	Lamp reflectors
Strength at low temperatures	• Strength increases and toughness is retained, unlike steel	Outboard marine parts and wind power station parts
Recyclability	• 100% recyclability with no property reduction • Recycling needs only 5% of energy for producing primary metal	100% recyclability has a major impact on environmental protection and the carbon footprint
Near net shape	• Minimum drafts • As cast bores • Minimum machine stock • As cast coarse threads in die casting	Transmission valves Transmission housings  Transmission valve

(*continued*)

Table 1.1 (continued)

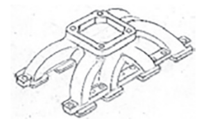
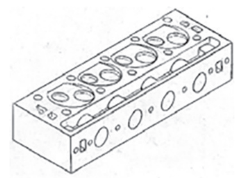
Advantages	Details	Typical applications
Complex shapes using sand cores	Sand cores enable castings with undercuts, pockets, profiled air and fluid passages	Intake manifolds Cylinder heads  Intake manifold  Cylinder head

Table 1.2 Aluminum casting limitations

Limitations	Detail
Cost	Cost is a critical component when deciding to convert to aluminum. Aluminum alloys are more expensive than ductile iron or stamped steel, per pound. Designers look for the value of the premium they pay for aluminum castings. The premium is justified if any of these objectives are met: • Vehicle mass reduction targets • Improved ride and handling of upscale or luxury vehicles • Higher acceleration in sports models • Vibration reduction of suspension • Reduction of unsprung mass in cornering • Increased payload or hauling requirements • Aesthetic or styling requirements Typically, if the overall vehicle mass needs to be reduced, the designers rank all the potential conversion candidates for styling as well as the least-risk, least-cost-premium, and maximum-mass-saving options. In sourcing decisions, they conduct a cost–benefit analysis before a final selection of the material. Most of the gasoline engines have aluminum cylinder heads. Automotive wheels rank high, based on styling opportunities. A high percentage of engines have aluminum blocks. Customers are willing to pay a premium for aluminum steering knuckles and brake calipers because of the potential for unsprung mass reduction.
Lower yield strength	Aluminum alloys for structural components typically have 70% of the yield strength of comparable ductile iron grades. Therefore, the replacing aluminum part has to be bigger to handle the same or similar load conditions. The packaging constraints need room to accommodate a larger-volume component. Sometimes this can be an issue.
Lower elastic modulus compared to steel	The Young's modulus of elasticity of aluminum alloys is about 35% of low carbon steel's modulus of elasticity. Stiffness is proportional to the modulus of elasticity, and therefore steel has a definite advantage over aluminum when stiffness is the dominating performance need. Depending on the relative costs of steel and aluminum, automakers have been forced to switch back and forth between steel and aluminum, incurring heavy expenses.
Specialized welding needs	Aluminum is more difficult to weld compared to steel. In the heat-affected-zone, the properties are impaired, especially if the components have been T6 heat treated. Sound welds need minimal to zero porosity at the weld interface, and this poses limitations for the assembly of components to produce a larger product, like a cross member. Also, welding a rolled or extruded member to a cast component poses some challenges.
Strength at elevated temperatures	Both yield and tensile strengths decrease with elevated temperatures, decreasing significantly above 100 °C (212 °F). The operating temperature is an important factor while evaluating an application.

- Computers and television equipment
- Power generation and transmission
- Marine applications
- Agricultural machinery
- Oil, gas and mining machinery
- Fluid handling equipment (pipes, fittings, pumps, valves)

The automotive sector has seen steady growth, sustained by the increase in number of vehicles produced globally and the expected growth of electric vehicles. Household appliances, refrigeration, and air-conditioning have experienced a spurt in demand, influenced by a global increase in standard of living and affluence.

Railroads and highway transportation are seeing a big opportunity for traction load reduction and mass savings as aluminum castings are substituted for iron and steel castings.

Breakthroughs in computerized process simulation and critical process improvements have expanded the use of aluminum in commercial and military aircraft bodies, aero engine parts, and weapon systems.

Medical imaging equipment and computers, television and other entertainment equipment, which combine style and fine finish, are seeing significant growth.

Clean energy power generation systems are requiring new power grids, which have high aluminum content. Marine and water sport markets see a significant potential growth in aluminum applications.

Agricultural machinery, fluid handling systems, and oil and gas industries are also projected to grow with increased use of aluminum, due to its several advantages for such applications.

1.5 Aluminum Conversions from Steel and Iron

The automobile industry has benefited significantly from the conversion of steel and iron parts to aluminum. Vehicle weights have been lessened and ride, handling, and performance have improved. Pollution has decreased, emission goals have been achieved, and material recycling has increased. Innovative designs have been developed and enhanced.

Conversion of engine blocks from cast iron to aluminum is reported to save up to 50% of the weight. When chassis and suspension parts are replaced by aluminum, weight savings range from 30 to 35%.

Aluminum has excellent durability, and its recyclability is a great advantage for reducing the carbon footprint. Currently, 75% of all aluminum used in automobiles is still in use because of its durability. Aluminum content in automobiles in Europe is projected to increase by 7 to 12% in the next four years. Subsequent years are projected to see a growth of at least 18%. Much of this growth comes from body struc-

Table 1.3 Successful conversions of aluminum from iron and steel

Group	Component	Conversion drivers
Chassis	Wheels	Aesthetics, unsprung mass reduction
	Brake calipers	Unsprung mass reduction
	Knuckles	Unsprung mass reduction
	Control arms	Mass reduction, ride handling improvement
	Lateral links	Mass reduction
	Rack and pinion housings	Mass reduction
	Master cylinder	Mass reduction
	ABS housings	Mass reduction
Body	Front cross member	Vehicle front-axle mass reduction
	Middle cross member	Body mass reduction
	Shock towers	Body mass reduction
	A & B pillars	Body mass reduction
	Instrument panels	Cabin noise reduction
Engine	Cylinder head	Front axle mass reduction
	Cylinder block	Front axle mass reduction
	Crank cases	Front axle mass reduction
	Oil pans	Front axle mass reduction
	Intake manifold	Front axle mass reduction
	Front cover	Mass reduction
	Water pump	Mass reduction
	Thermostat housing	Mass reduction
	Oil filter adapter	Mass reduction
	Brackets	Mass reduction
	Cam cover	Mass reduction
	Timing chain cover	Mass reduction
	Compressor housing	Mass reduction
	Compressor scrolls	Mass reduction
	Piston	Performance improvement
Transmission	Transmission case	Mass reduction
	Differential carrier	Mass reduction
	Transmission valves	Mass reduction

tures, as manufacturers replace steel subframes and shock towers with aluminum vacuum die cast castings (Source Ref.1). Currently, the market penetration of aluminum in chassis and suspension parts is only about 55 to 60% globally.

Automakers itemize potential conversions and conduct a cost premium–benefits potential analysis to rank and select the conversions that offer the best value for the premium paid.

Table 1.3 lists some of the successful conversions from steel stampings and iron castings to aluminum castings in North America. The conversion drivers that motivate the automotive designers are highlighted.

Chapter 1: Aluminum Casting Applications

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