# GUIDELINES FOR HANDLING MOLTEN ALUMINUM



FOURTH EDITION
MAY 2016

The Aluminum Association

69

# Guidelines for Handling Molten Aluminum Fourth Edition - 2016

Editor – Curt Wells, The Aluminum Association

Editorial Board

Brad Burridge – Novelis
Jim Brock – Alcoa
Vincent DiCerbo – Constellium
Mark Eliopulos – Kaiser Aluminum
Les Kirby – Aluminum Cast Shop Consultants, LLC
Jake Niedling – Consultant
Jack Patrick – Sapa
Ray Richter – Aluminum Cast Shop Consultants, LLC
Jeff Wiesner – Alcoa
John Zeh – Logan Aluminum
Mike Zoll – Novelis

The guidelines and recommendations in this book are based on information believed to be reliable and are offered in good faith but without guarantee. The precise causes of molten metal explosions, and the conditions under which problems arise, have been long studied but are still not fully understood. The operational conditions which exist in individual plants and facilities vary widely, and thus no definitive standards exist for handling molten aluminum. Accordingly, the Aluminum Association and its member companies assume no responsibility or liability for the completeness of the data or the general applicability of the guidelines and recommendations herein, which are based on state of the art knowledge but may not be appropriate in all situations. The photographs in this publication are illustrative only and are not intended to represent standard safety practices utilized in the industry. Users of these Guidelines should adapt the recommendations herein, as appropriate, to the precise conditions of the individual facility under consideration and should always exercise independent discretion in establishing plant or facility operating procedures. No warranty, express or implied, is made of this information by the Aluminum Association or by any of its member companies.

**© Copyright 2016, The Aluminum Association, Inc.**
**Unauthorized reproduction by photocopy or any other means is illegal**

# Foreword

The original *Guidelines* were first issued by the Aluminum Association in 1980, quickly followed by a first revision in 1982. In 1990, a second edition was published which presented information and practices available up to that time. In 2002, a third edition was released which was reflective of the ongoing evolution of molten metal safety management programs.

It is clear from the revision history noted above that practices and equipment for melting and casting aluminum are continually being modified and improved for a variety of reasons. In addition, information from industry reporting programs and research efforts spearheaded by the Aluminum Association and its member companies is continually being generated Therefore, in order to capture and disseminate updated information in these areas, these guidelines undergo periodic review and revision toward the goal of making the aluminum industry workplace safer.

This fourth edition of the *Guidelines* was prepared with technical input and review by industry representatives with considerable expertise in all aspects of handling molten aluminum. Basic information has been retained, but considerable change has been made to the organization and presentation of the subject matter. New sections have been added and the existing sections have been significantly updated and expanded to incorporate the new information available since publication of the third edition. In particular, new information has been added on 1) the management of the hazards presented by combustible aluminum dust, 2) the unique hazards of managing aluminum-lithium alloys, and 3) mobile equipment safety in the casthouse.

# Table of Contents


Contributors ..... i

Foreword ..... ii

I. **INTRODUCTION** ..... 1

Section 1: Introduction ..... 3

Section 2: Scope, Format, and Organization of the Guidelines ..... 4

II. **SAFETY MANAGEMENT** ..... 5

Section 3: Safety Programs and Training ..... 7

III. **GENERAL INFORMATION AND DESIGN CONSIDERATIONS** ..... 9

Section 4: Hazards in Handling Molten Aluminum — General ..... 11

Section 5: Physical and Chemical Properties of Molten Aluminum ..... 11

Section 6: Suggested Purchase Specifications for Charge Materials ..... 12

Section 7: Receiving, Inspection, Storage, and Drying of Scrap and all other Components of the Furnace Charge ..... 12

Section 8: Melting, Melt Treatment and Transfer, and Casting Processes ..... 13

Section 9: Considerations in Design of Equipment and Controls ..... 18

Section 10: Housekeeping ..... 25

IV. **PERSONAL PROTECTION** ..... 27

Section 11: Personal Protective Clothing and Equipment ..... 29

V. **MELTING, MELT TREATMENT, AND TRANSFER OPERATIONS** ..... 39

Section 12: Receiving, Inspection, and Storage of Materials to be Melted ..... 41

Section 13: Pre-melting Precautions ..... 42

Section 14: Drying of Material Charged into the Furnace ..... 46

Section 15: Handling and Processing of Sow, T-Ingot and Billet ..... 48

Section 16: Melting Operations including Treatment of Metal in the Furnace ..... 50

Section 17: In-line Melt Treatment Operations ..... 53

Section 18: Melt Transfer Operations — General ..... 54

Section 19: Metal Transfer during Casting of Process Ingot ..... 56

VI. **CASTING OPERATIONS** ..... 59

Section 20: SOP's for Casting and Precasting Precautions ..... 61

Section 21: Casting of Process Ingot – General ..... 63

Section 22: Direct Chill (DC) Casting – Conventional ..... 63

Section 23: Hot Top Casting / Level Pour Casting ..... 66
Section 24: Electromagnetic Casting (EMC) ..... 69
Section 25: Aluminum – Lithium Casting ..... 72
Section 26: Other Casting Systems ..... 75
Section 27: Cleanup of Metal Spills ..... 75

**VII. PROTECTIVE COATINGS: CASTING PITS AND EQUIPMENT** ..... 77

Section 28: Protective Coatings for Casting Pits and Equipment ..... 79

**VIII. CASTHOUSE MOBILE EQUIPMENT** ..... 81

Section 29: Casthouse Mobile Equipment ..... 83
Section 30: Pedestrian Interaction / Segregation ..... 83
Section 31: Equipment Specifications ..... 84
Section 32: Qualification, Training and Evaluation ..... 86
Section 33: Operating Guidelines ..... 87

**IX. EXPLOSIONS INVOLVING MOLTEN ALUMINUM** ..... 89

Section 34: Explosions Involving Molten Aluminum ..... 91
Section 35: Thermite Reactions ..... 92
Section 36: Research on Molten Aluminum-Water Explosions ..... 93
Section 37: Molten Metal Incident Reporting ..... 97

**X. EXPLOSIONS INVOLVING COMBUSTIBLE DUST** ..... 99

Section 38: Combustible Dust in the Casthouse ..... 101
Section 39: Hazards ..... 101
Section 40: Preventive Measures: ..... 103
Section 41: Dust Incident Response ..... 103

**XI. REFERENCES AND TRAINING AIDS** ..... 105

Section 42: References ..... 107
Section 43: Videos and Training Aids on Preventing Molten Aluminum-Water Explosions ..... 109

# Figures


1 Figure 1 Aerial view of a casthouse following a molten metal explosion ..... 3

1 Figure 2 Ground level view of a casthouse following a molten metal explosion ..... 4

8.1 Figure 1 Charging a Furnace from a Transfer Crucible..... 13

8.2 Figure 2 Typical Melting, Holding, Casting Process Flow Sheet..... 14

8.3.5 Figure 1 One Type of Continuous Strip Casting Machine..... 16

8.3.6 Figure 1 A Robotic Pig Ingot Casting Machine with Skimming and Metal Filling Control ..... 17

8.3.6 Figure 2 A Modern Sow Casting Operation ..... 17

9.3.4 Figure 1 Billet Base Plate with Starting Blocks..... 21

9.3.4 Figure 2 DC Casting Pit with Low Water Level in Pit..... 22

9.3.4 Figure 3 DC Casting Pit with High Water Level in Pit ..... 22

11.2.2 Figure 1 Secondary Protective Clothing ..... 30

11.2.2 Figure 2 Aluminized Primary Protective Clothing ..... 31

11.2.2 Figure 3 Zirpro Wool Primary Protective Clothing..... 31

11.2.2 Figure 4 Aluminized Primary PPE in Casthouse Use..... 31

11.2.4 Figure 1 Face shield that protected employee from eye damage and facial burns during a drain pan molten metal explosion ..... 33

11.3 Figure 1 FR garments worn by employee exposed to molten metal from a drain pan explosion. Use of FR garments minimized the extent of burn injuries. ..... 34

11.3 Figure 2 Graph of Casting Explosions by Casting Segment ..... 34

11.3 Figure 3 Photo sequence showing an end of cast drain pan explosion in progress. Use of proper PPE prevented significant employee injury. ..... 35

13.1.1 Figure 1 Examples of cavities, cracks and double poured sows that can contain moisture..... 42

13.1.2 Figure 1 Examples of cavities and cracks that can contain moisture and a double poured sow. ..... 43

13.1.3 Figure 1 Examples of oxidized copper and magnesium, magnesium shrinkage cavity ..... 44

13.1.3 Figure 2 Example of a zinc ingot with a shrinkage cavity ..... 44

13.2 Figure 1 Salt flux on top of and imbedded into RSI. The dark material identified by the arrow was found to be flux salt. ..... 45

14.1 Figure 1 Example of a commercially available sow drying system. The system shown is a natural gas fired dryer with positive pressure and recirculation fans. ..... 48

16 Figure 1 Melting explosions data ..... 51

16 Figure 2 Force Level Explosions by Operation ..... 51

16.4 Figure 1 Skimming Dross from a Furnace by Mechanical Skimmer ..... 52

18.4.Figure 1 Force Level Explosions by Operation ..... 55

18.4 Figure 2 Injuries by Operation ..... 55

18.4 Figure 3 Transfer Explosions by Equipment Type Involved ..... 56

20 Figure 1 DC/HDC/EMC Explosions by Cast Segment ..... 61

22.1 Figure 1 Typical DC Casting Station Billet ..... 64

22.1 Figure 2 Typical DC Casting Station Slab/Sheet Ingot ..... 64

22.2 Figure 1 Schematic of Horizontal DC Casting Station ..... 65

22.2 Figure 2 Section of Horizontal DC Casting Station and Water Basin ..... 65

23.1 Figure 1 Schematic of a Hot Top DC Casting System ..... 67

23.1 Figure 2 Schematic of Hot Top Mold with Air Injection ..... 67

24.2 Figure 1 Typical Automated EM/DC Casting Sequence ..... 70

24.3.2 Figure 1 Automated Safety Stops in EM/DC Casting ..... 71

31.1 Figure 1 Charging Scrap into a Remelt Furnace Using a Shielded Fork Truck ..... 85

31.1 Figure 2 Fork Truck Following a Furnace Explosion ..... 85

31.1 Figure 3 Foundry Package Equipped Fork Truck in Use ..... 85

34 Figure 1 Explosion Characterization ..... 91

37 Figure 1 Molten Metal Incident Reporting Form ..... 98

38 Figure 1 Aluminum Dust/Fines ..... 101

39 Figure 1 The Fire Triangle ..... 101

39 Figure 2 The Explosion Pentagon ..... 102

40 Figure 1 Aluminum Dust Cloud ..... 103

# I

# INTRODUCTION

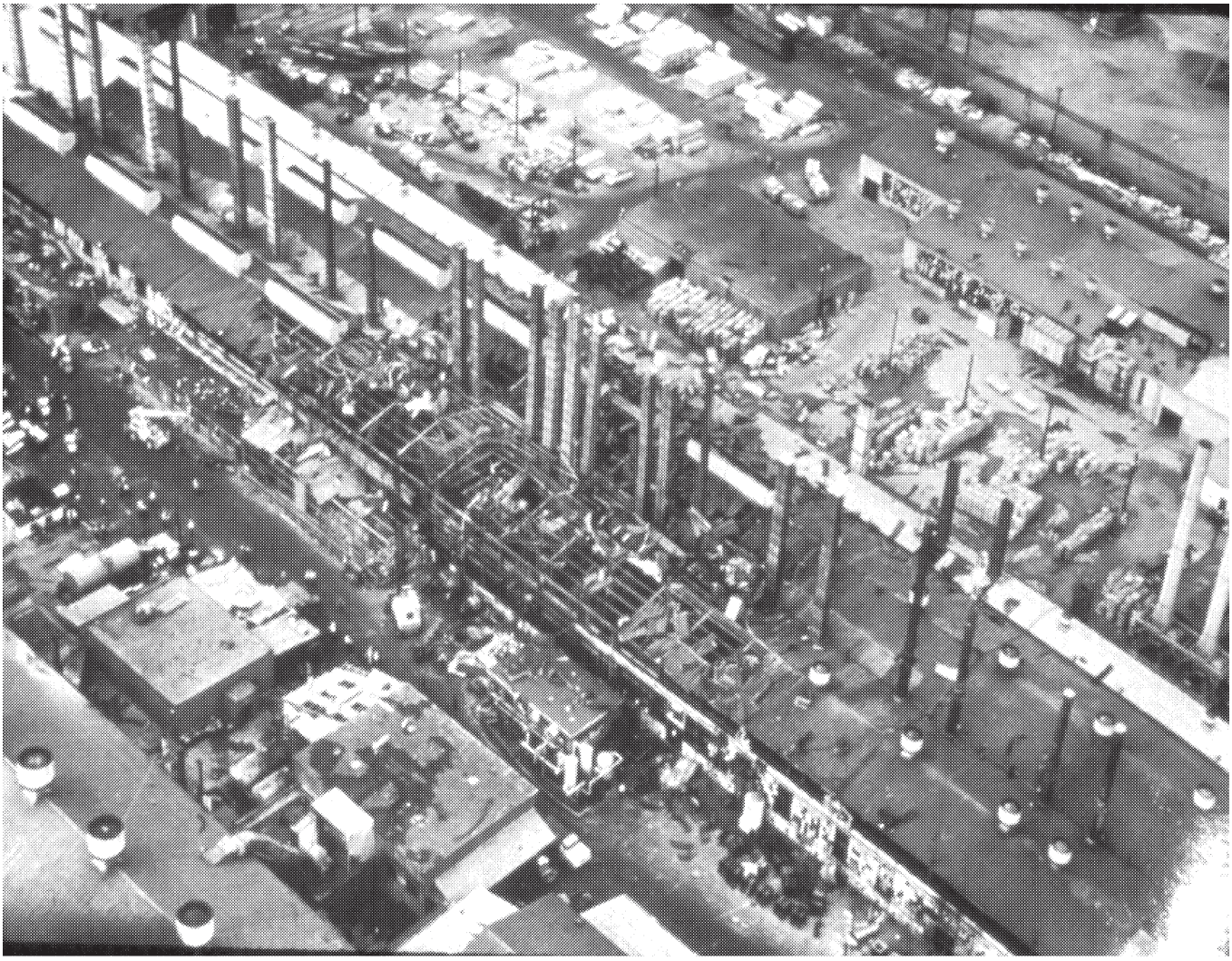


# Section 1
# Introduction

As evidenced by globally available injury and illness statistics gathered by the Aluminum Association and other sources, aluminum plants are relatively safe, healthy workplaces. However, every industry has its potential hazards depending on the processes and/or products involved. The aluminum industry is no exception.

Billions of pounds of aluminum are melted and cast safely every year in cast shops, foundries, recycling and reclamation plants all over the globe. However, there are inherent hazards in handling molten aluminum, just as there are in virtually any activity. These hazards can be minimized and eliminated by careful attention to safe handling practices.

Failure to use proper procedures in melting and casting aluminum can be dangerous. Contact with molten aluminum can burn personnel or set materials on fire. Mixing water and many chemical substances or contaminants with molten aluminum can cause explosions. These explosions can range widely in violence and can result in injury or death as well as significant destruction of equipment and plant facilities. Examples of the damage resulting from catastrophic molten metal explosions in the aluminum industry are shown in 1 Figure 1 and 1 Figure 2.



**1 Figure 1 – Aerial view of a casthouse following a molten metal explosion**