Journal of Materials Processing Technology 237 (2016) 188–196

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

# Foundry sand core property assessment by 3-point bending test evaluation

Bernhard J. Stauder[a,*], Hubert Kerber[b], Peter Schumacher[c]

[a] Nemak Linz GmbH, A-4030 Linz, Zeppelinstraße 24, Austria
[b] Austrian Foundry Research Institute—ÖGI, A-8700 Leoben, Parkstraße 21, Austria
[c] Montanuniversität Leoben, Chair of Casting Research, A-8700 Leoben, Franz-Josef-Str. 18, Austria

ARTICLE INFO

*Article history:*
Received 25 September 2015
Received in revised form 1 June 2016
Accepted 4 June 2016
Available online 23 June 2016

*Keywords:*
Casting
Sand core testing
Load curve evaluation
Work of fracture
Core deformation
Quality control

ABSTRACT

Improved understanding of foundry sand core properties is a key requirement for high precision casting process development. The present work demonstrates the potential to evaluate mechanical and functional sand core properties using precisely acquired 3-point bending test load curve data applying standard bending test geometries.

Four organic binder systems have been investigated. Further to bending strength and the elastic modulus, which can be directly derived from the load curves, a load curve pre-treatment to eliminate sample settlement effects was applied for a corrected deflection and stiffness analysis. The consumed mechanical work shows characteristic elastic and plastic work portions until fracture, which are specific for different sand cores, respectively their condition. Dimensionless indicators to quantify core brittleness have been developed based on curve and on work parameters.

In general for mechanical evaluations of resin bonded sand cores, visco-plastic effects need to be considered, as for not fully hardened binder systems decreased strength, deflection and work of fracture were observed at lower load speeds.

The benchmark results show that the load curve evaluation concept is a suitable tool to analyse foundry sand core properties more sensitively.



## 1. Introduction

Metal casting using sand cores allows to produce complex components with internal geometries in high volumes, typical examples are combustion engine cylinder heads and blocks. Fig. 1 shows a cylinder head casting from Al and the required sand cores for the internal surfaces, while in Fig. 2 a preassembled sand core package is shown prior to casting.

The influence of technology, materials and process parameters on dimensional accuracy of near-net-shaped casting products has been systematically compiled by Campbell (2000). The foundry industry is forced to steadily improve process capabilities to facilitate light-weight, respectively thin walled castings, to contribute to ever tightening emission legislation requirements (Lellig et al., 2010). The importance of sand core technology development is highlighted.

### 1.1. Foundry sand core technology and developments

The development of new binder systems, such as chemically bond sand cores was intensively characterized by Bindernagel (1983). A comprehensive collection of sand and binder systems was given by Flemming and Tilch (1993). Mechanical properties of sand cores are mainly qualitatively described and no property related material laws are proposed.

In automotive foundries the most widely applied core manufacturing processes are the organic Coldbox, Warmbox, and Hotbox core production processes. Process descriptions are given by Langer and Dunnavant (2011) and Brown (2010). Currently a substitution process of organic by inorganic binders having less odour development is ongoing. However, because of different properties, process relationships for such new binder types require increased attention on the process control (Weissenbek et al., 2011). Recently Czerwinski et al. (2015) reviewed the state of the art of foundry core technology for several relevant organic and inorganic binder systems used in various foundry applications.

Summarized, fundamental requirements into sand core properties are:

* Corresponding author.
*E-mail addresses:* bernhard.stauder@nemak.com, bernhard.stauder@aon.at (B.J. Stauder).

http://dx.doi.org/10.1016/j.jmatprotec.2016.06.010
0924-0136/

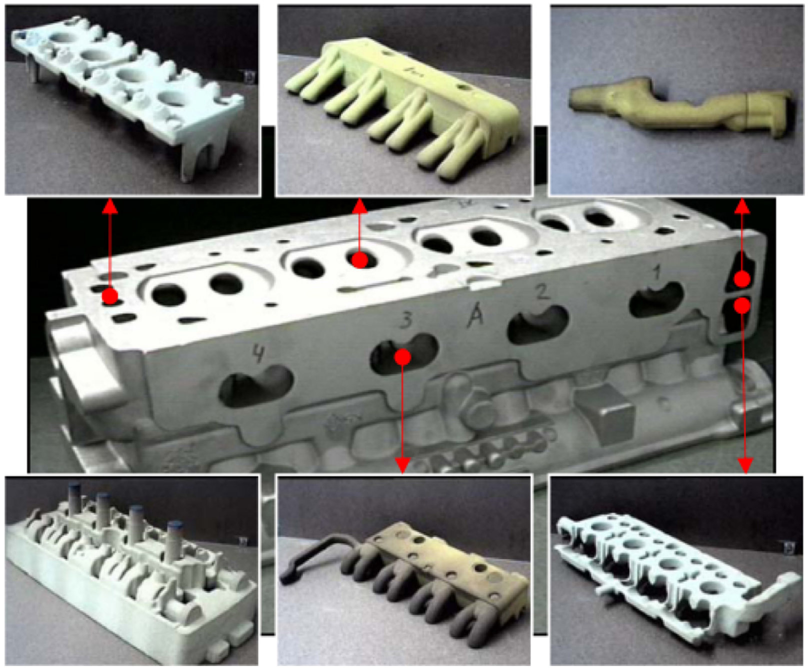

**Fig. 1.** Illustration of a medium complexity car cylinder head in cast Al and the required sand cores to shape its cavities (Sobczyk, 2008).

- Sufficient strength to allow handling and manipulation operations;
- High resistance against humidity during core storage.
- High erosion and penetration resistance and no chemical interaction with the cast metal to deliver a good casting surface quality.
- Low gas evolution and high gas permeability to avoid casting defects.
- High bending strength: bending is the most critical load type for sand cores under casting conditions. It can be imposed by clamping forces, thermal load, flow drag and buoyancy loads.
- Easy shake-out after casting to obtain sand-free cast parts.
- A good recycling ability of used foundry sand.
- Environmentally friendly core systems with low odour development.

### *1.2. Research on sand cores under thermal load*

Generally only little research on sand core behaviour under casting conditions can be found in the literature. Some examples of foundry sand core investigations under realistic loading conditions and the applied types of modelling data are given here.

The deformation of a complex cylinder head water-jacket core has been studied by Dong et al. (2010). Their used material data were based upon bending tests and upon validations using a cup type core for casting trials. Critical regions in the casting due to core bending could be predicted. Motoyama et al. (2013) investigated residual stresses of castings influenced by counter forces from furanic moulds applying specifically developed in-situ measurement of the transmitted loads. The material properties for modelling were obtained by compressive tests.

Stachowicz et al. (2011) have described cohesive and adhesive fracture mechanisms of inorganically bonded cores. Even sand grain cracking was observed, but not below a thermal load of 1100 °C. High temperature bending tests to describe the properties of a novel starch binder for foundries were performed by Zhou et al. (2009). They observed sand core damage through binder cracking and delamination.

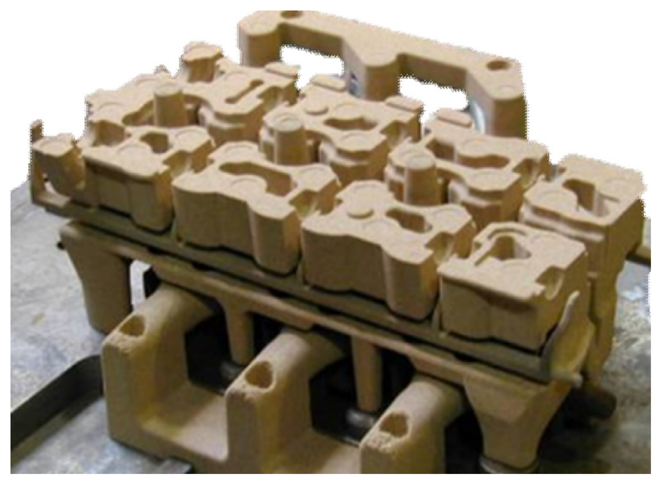

**Fig. 2.** Sand core package for an intricately shaped cylinder head prepared for casting by the Rotacast process (Gosch and Stika, 2005).

### *1.3. Testing of sand cores and other bonded granular materials*

Testing methods for foundry sand cores and other relevant material types with low plastic deformation will be discussed in the following.

Within the foundry industry the standards of sand core testing were established in the middle of the last century, as documented by American Foundrymen's Society – AFS – (Dietert, 1950). Bending tests are the most widely applied quality control for foundry sand cores, described by AFS (1962) and similarly by the German standard (VDG, 1999). In both, no load curve acquisition is required and the beam deflection can be manually driven. The loading velocity is not quantified, but should be constant and smoothly applied. The bending strength is calculated from the maximum load based upon linear elastic continuum mechanical relations.

To enable sand core deformation studies additional information from load-deflection curves is required. (Kerber et al., 2014) reviewed the conventional testing methods and standards