

## Optimizing curing parameters to enhance the compressive strength and toughness properties of Resin-Coated Sand (RCS) in foundry applications

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### Abstract

Conventional heating methods remain prevalent among Small and Medium-Sized Enterprises (SMEs) for aluminum mold thermal regulation during Resin-Coated Sand (RCS) core production. Inconsistent thermal regulation significantly alters the characteristics of RCS cores. This study aims to investigate the effect of curing parameters on the compressive strength and toughness of the RCS. The RCS specimens were prepared using the aluminum mold that underwent controlled thermal treatment in an electrical furnace. The thermal treatment was performed by processing specimens across a curing temperature range of 200-300°C and varying curing time from 3 to 15 minutes. HDPE polymer was proposed as the RCS binder. Compressive and impact tests were carried out to determine the characteristics of RCS. The results showed that a non-linear relationship between curing parameters and mechanical properties. Although moderate curing time and higher temperatures initially improve compressive strength and toughness, exceeding optimal thresholds leads to the degradation of these mechanical characteristics. The highest mechanical properties (compressive strength = 38.4 MPa, toughness = 0.43 MPa) are achieved through a curing temperature of 250°C and a curing time of 9 minutes. This study provides valuable insights into determining the optimal parameters for processing RCS cores or molds with superior compressive and toughness properties

### Keywords:

Resin-coated sand, RCS, compressive strength, toughness, curing temperature, curing time.

### 1 Introduction

Resin-Coated Sand (RCS) is increasingly utilized in foundry industries owing to their capability for high-volume production and complex shape casting [1]. RCS exhibits high strength, excellent pourability, and superior shakeout properties. These beneficial characteristics enable the production of intricate solid and hollow cores, which produce castings with smooth surface finishes, tight dimensional tolerances, and a good level of precision [2], [3]. RCS consists of silica sand particles enveloped by a resin binder system. The manufacturing process involves heating silica sand to an optimal temperature before introducing it into a mixing apparatus, where precise quantities of therosetting resin and supplementary additives are systematically incorporated. Therosetting resins undergo a solid-to-liquid phase transition when subjected to elevated temperatures before cross-linking. The resin system undergoes significant viscosity escalation, ultimately solidifying through cross-linking reactions and hardening the core or mold [4], [5].

Gas stove burner (Fig. 1) is one of the most popular products in small and medium-sized foundry enterprises. The current production capacity for gas stove burners is approximately 300 pieces per day, far below the level of consumer demand. This problem is primarily caused by limited manufacturing capacity in fabricating resin-coated cores for gas stove burner molds.



Fig. 1. Gas stove burner

Small and Medium-Sized Enterprises (SMEs) in foundries generally use conventional heaters to heat the aluminum mold during the production of RCS cores, as displayed in Fig. 2. As a result, maintaining the proper heating temperature becomes challenging. If the temperature is insufficient, the RCS cores develop a light-yellow color, become brittle, and fail to withstand the liquid aluminum during the casting process. Conversely, excessive heat causes the RCS cores to darken from deep yellow to black, making them hard and brittle, which leads to breakage during the casting process. Additional negative effects include significant thermoplastic relaxation and gas release during the pouring process [1]. The RCS core on the aluminum mold can be seen in Fig. 3.



Fig. 2. Heating the aluminum mold using a conventional heater



Fig. 3. The RCS core on the aluminum mold

A thorough understanding of the resin curing mechanism is essential for both quality control of sand cores/molds and enhanced production efficiency in casting operations since the resin's curing mechanism significantly influences the characteristics of fabricated shell cores and molds [2]. The degree of cross-linking can be precisely controlled through optimal adjustment of both curing time and curing temperature. The curing time represents the duration during which RCS undergoes thermal exposure. The curing temperature denotes the controlled heat level necessary to facilitate the curing mechanism in the resin-sand system. Continuous monitoring of both curing time and curing temperature during core production is critical for attaining optimal mechanical properties, ensuring the core can endure handling stresses and molten metal forces during casting operations [1], [6].

Substantial studies have been performed on advancing RCS technology for foundry application, with numerous studies investigating various binder systems and processing methods. Several studies [7], [8] were performed to investigate the behavior of phenol-formaldehyde novolac resins for foundry application. Their investigation can be used for determining the optimal curing temperature in casting. The typical curing temperature range is 204 to 316 °C [4]. A study conducted by Chun-Chiao and Jie [7] reported that the curing temperature must be maintained between 150°C and 300°C. Their studies showed that the shell cores achieve maximum strength at 260°C without causing thermal degradation of the cross-linked resin. Khandelwal et al. [9] evaluated the effect of grain size, binder, and curing time on the sand mold characteristics. The results showed that sand mold strength increases with higher binder content and longer curing times, but decreases with reduced sand grain size. A consistent increase in sand core shrinkage corresponding with elevation of all three investigated parameters (sand grain size, binder percentage, and curing time). Ultimately, optimal mold properties were achieved with 2.4% binder content, 40 GFN sand, and 4 hours curing time, resulting in peak maximum shear strength (16.44 kg/cm<sup>2</sup>), core hardness of 81.4, and mold shrinkage measuring 51 μm. Sirivimonpan and Osothsilp [10] investigated the correlation between the flexural strength of RCS and the compositional ratios of various sand and resin types. The flexural strength ranges between 16 – 82 kgf/cm<sup>2</sup>, demonstrating significant variability across test specimens. Additionally, Budavári and Varga [1] conducted a systematic investigation into how curing time and temperature parameters influence the hot distortion characteristics of RCS systems. Their study revealed that higher curing temperatures and curing time result in increased core deformation and reduced thermal strength in resin-bonded sand system. A novel manufacturing technique for high-temperature-resistant RCS (stable to 1000°C) was introduced by Kim et al. [11]. Their findings showed that the mold displayed remarkably stable thermal characteristics, with only 0.23% linear dimensional change at 1000°C. Moreover, Kmita et al. [12] examined thermal decomposition mechanisms of foundry resins. Their study reported that pyrolysis gases contain predominantly toxic compounds posing dual risks to humans and ecosystems. Thus, their findings suggest maintaining molding sand temperatures below 400°C to prevent material degradation. Besides that, optimal foundry practice requires rapid mold removal after solidification, as the emissions reach maximum levels during initial pouring and mold separation.

The development of the RCS core or mold have been extensively studied by other scientists. However, there is a lack of studies on the effect of curing parameters on the mechanical properties of the RCS. Existing research predominantly focuses on thermal deformation and decomposition behaviors of molding sand. To address this research gap, this study investigates the effect of curing parameters on the compressive strength and toughness of the RCS. A systematic curing parameter study was conducted by processing specimens across a curing temperature range of 200-300°C (in 25°C increments) coupled with varying curing time from 3 to 15 minutes (in 3-minute intervals). The compressive strength and toughness of the RCS were

assessed through mechanical tests, such as compressive and impact tests.

## 2 Experimental procedure

### 2.1 Specimen preparation

The specimens were prepared using commercial coated resin, with compositional ratio of silica sand 80%, High Density Polyethylene (HDPE) 10%, and bentonite 10% (by weight). The mixture of RCS was homogenized through continuous mechanical stirring until achieving a uniform consistency. The homogeneous mixture was carefully transferred into the aluminum mold cavity and mechanically clamped under lid pressure. The aluminum mold has four identical cavities (12.7 mm x 12.7 mm x 25.4 mm), facilitating quadruplicate sample preparation per thermal treatment, as displayed in Fig. 4a. An electrical heating furnace by Naber (Fig. 4b) was used to treat the specimens, with a maximum temperature capacity of 1050°C. Electrical heating furnace provides superior temperature control, offering more precise adjustability for consistent thermal processing. An initial heating phase was implemented, holding the electrical furnace at 200°C for 3 minutes before further thermal processing. The prepared mold was then inserted to the electrical furnace with variations in curing temperature and curing time as presented in Table 1. Upon completion of the thermal treatment, each specimen was gently removed from the aluminum mold. Three specimens were prepared for each test variation (Fig. 5).

Table 1. Variations in specimen treatment

| Group | Curing Temperature                | Curing Time                         |
|-------|-----------------------------------|-------------------------------------|
| I     | 200°C, 225°C, 250°C, 275°C, 300°C | 9 min                               |
| II    | 250°C                             | 3 min, 6 min, 9 min, 12 min, 15 min |

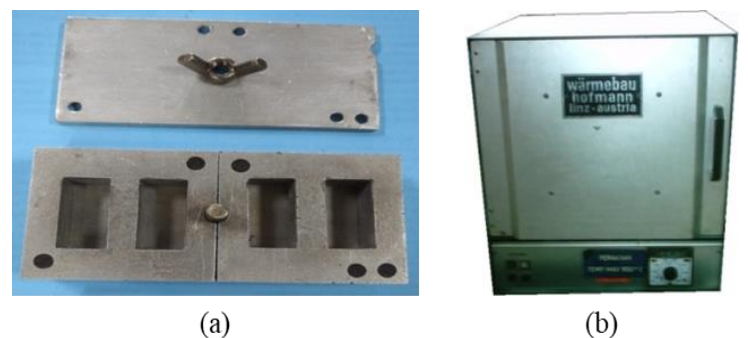


Fig. 4. Specimen preparation equipment. a) Aluminum mold, b) Electrical furnace

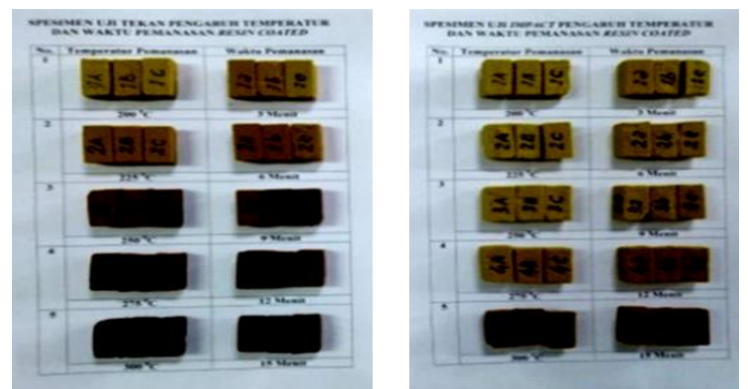


Fig. 5. Resin-coated specimen

### 2.2 Mechanical testing method

Mechanical testing was performed in order to assess the effect of curing temperature and curing time on the compressive properties and toughness of the RCS. The mechanical testing included a compressive test and an impact test. A compressive test was carried out using a universal testing machine UPH 100 KN, by Tarno Grocky (Fig. 6a), conforming to ASTM D695. The impact test was conducted according to ASTM D256 standard, utilizing the impact testing machine (No. 48-4.78 I-74 0 13 S-48-5) configured with a

hammer mass of 25.7 kg and pendulum length of 0.75 m, as depicted in Fig. 6b.



Fig. 6. Testing equipment. a) Universal testing machine, b) Impact testing machine

### 3 Results and discussion

#### 3.1 Effect of curing temperature

In this section, the effect of curing temperature on the mechanical properties of RCS is discussed. Curing time of 9 minutes was maintained while curing temperature was varied across the RCS specimens. Experimental results in terms of compressive strength and toughness of RCS at different curing temperatures are displayed in Fig. 7.

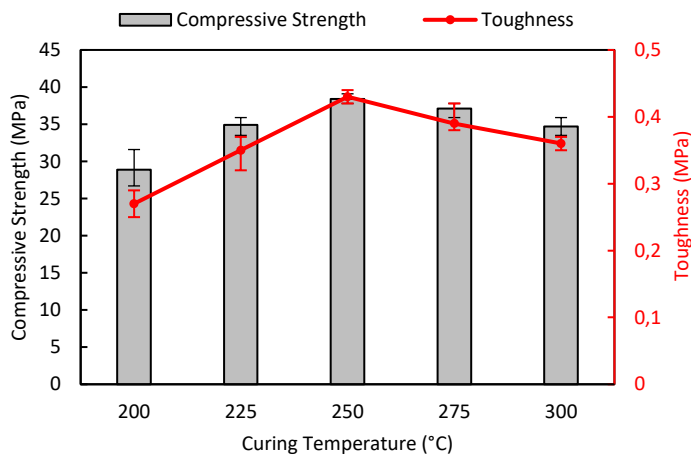


Fig. 7. Effect of curing temperature on the mechanical properties of RCS

The complete experimental data can be found in the supplementary (**Error! Reference source not found. - Error! Reference source not found.**). As shown in Fig. 7 At a 200°C curing temperature, the RCS achieves only 28.9 MPa compressive strength due to incomplete binder activation. Inadequate bonding between bentonite and the HDPE matrix, particularly in the core regions, results in heat transfer limitations that prevent optimal HDPE-bentonite interface formation. At 225°C, the HDPE matrix undergoes complete melting, significantly improving its interfacial bonding with silica sand particles. This enhanced binder distribution results in a 21% compressive strength increase to 34.9 MPa compared to 200°C specimens. At 250°C, the HDPE-bentonite interfacial bonding zone expands significantly, achieving complete cross-sectional coverage and increasing a 38.4 MPa compressive strength, representing a 39% enhancement compared to 200°C specimens. These results align with the 260°C optimum reported by Chun-Chiao and Jie [7], whose comprehensive characterization of RCS confirmed maximum compressive strength and toughness within this curing temperature range. Elevated temperatures beyond 275°C induce thermal degradation of HDPE, resulting in progressive strength reduction from 37.1 MPa at 275°C to 34.7 MPa at 300°C due to polymer evaporation and increased material fragility.

Fig. 7 demonstrates a consistent correlation between toughness and compressive properties, with both mechanical properties exhibiting parallel responses to curing temperature variations. The synchronous peaking of these properties at 250°C is followed by

identical degradation trends. The highest toughness of RCS was 0.43 MPa, obtained at a curing temperature of 250°C, whereas the RCS processed at 200°C exhibited the lowest toughness value of 0.27 MPa.

#### 3.2 Effect of curing time

Previous studies revealed that curing time affects the specimen's mechanical properties [9], [13], [14], [15]. In this section, the results of compressive and impact tests are analyzed, particularly regarding how curing time affects the mechanical properties of RCS. Different curing times were applied to RCS specimens cured at temperature 250°C. As presented in Fig. 8, the RCSs exhibit varying compressive strength and toughness depending on their curing time. The compressive strength of RCS with curing time of 3 min, 6 min, 9 min, 12 min, and 15 min are 32.8 MPa, 34.7 MPa, 36.3 MPa, 35.7 MPa, and 34.7 MPa, respectively. The compressive test results are in line with the study conducted by Khandelwal and Ravi [9], which found that the longer curing time increases the resistance of the RCS to compressive load. The continuous crosslinking of HDPE under thermal exposure leads to an increase in compressive strength, although at a certain point, the compressive strength tends to decrease. This is due to the HDPE binder undergoes thermal degradation at elevated temperature, resulting in RCS embrittlement, leading to decrease in the RCS's mechanical properties.

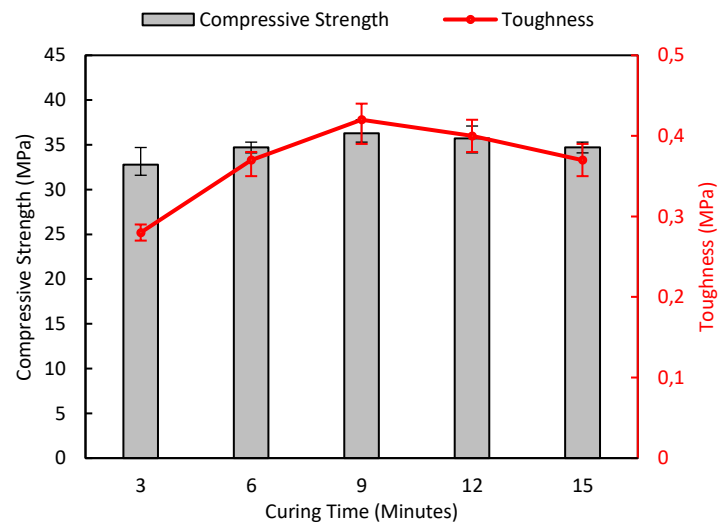


Fig. 8. Effect of curing time on the mechanical properties of RCS

As shown in Fig. 8 Curing time also influences the toughness properties of RCS. Toughness represents a material's capacity to undergo plastic deformation while absorbing mechanical energy before fracture [16]. The toughness enhancement follows the same curing-time dependence observed in compressive properties, suggesting similar strengthening mechanisms in the RCS. Optimal toughness (0.42 MPa) was achieved at a 9-minute curing time. Prolonged curing times increase network density through additional crosslink formation [8], subsequently reducing ductility in the RCS.

### 4 Conclusions

This study examines the effect of curing parameters on the compressive strength and toughness of the RCS. HDPE is introduced as a novel binding agent for RCS applications in aluminum foundries. These findings provide practical guidelines for SMEs' aluminum foundries to optimize RCS core production using an electrical furnace, minimizing defect rate in RCS production. This study establishes that optimal mechanical properties of RCS are achieved at 250°C with a curing time of 9 minutes. Under these processing conditions, the RCS demonstrates a compressive strength of 38.4 MPa and a toughness of 0.43 MPa. In addition, the interfacial bonding between HDPE and silica sand exhibits strong curing parameters dependence, with insufficient bonding occurring below the optimal temperature range and thermal degradation breaking bond integrity at elevated temperatures.

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