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Use of rice husk as hot tipping on steel casting parts

Utilización de la cáscara de arroz como cobertura en la fundición de piezas de acero

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Abstract

The use of feeding aids in the foundry process has become widespread globally recent decades, leading to increased efficiency. This article examines the characterization of rice husks, their ashes, and their positive impact as hot topping on the efficiency of open risers in casting cylindrical parts made of AISI 1045 steel. The rice husks were analyzed through X-Ray Diffraction test, Thermal-Gravimetric Analysis, and Differential Thermal-Gravimetric Analysis, while the ashes were characterized using X-Ray Diffraction. The analyzed rice husks were found to contain cellulose and low crystallinity silicon, whereas the ashes primarily consisted of cristobalite and tridymite. It was observed that the thermal decomposition of rice husks occurs in three stages, with approximately 81% of the mass lost during their combustion as hot topping on liquid steel. The location of cavities contraction in the risers of casting parts was made through longitudinal cut of the part-riser system. The increase in the rice husks topping layer thickness positively influences the concentration of these cavities on the upper surface and enhances the feeder's efficiency.

Keywords: rice husk; feeding aids; exothermic materials; isothermic materials; metallic efficiency.

cáscara de arroz; auxiliares de alimentación; materiales exotérmicos; materiales isotérmicos; eficiencia metálica.

Resumen

La utilización de materiales auxiliares en los procesos de fundición se ha generalizado en las últimas décadas en todo el mundo, debido a que permite aumentar la eficiencia de los mismos. En este artículo se expone la caracterización de una cáscara de arroz y sus cenizas. Se evaluó su influencia como cobertura en la eficiencia de alimentadores abiertos en la fundición de piezas cilíndricas de acero AISI 1045. La cáscara de arroz se caracterizó mediante ensayos de Difracción de Rayos X, Análisis Termogravimétrico y Termogravimétrico Diferencial, mientras que sus cenizas se caracterizaron mediante difracción de rayos X. La cáscara de arroz evaluada contenía celulosa y sílice de baja cristalinidad y sus cenizas contenían fundamentalmente cristobalita y tridimita. Se determinó que la descomposición térmica de la cáscara de arroz ocurre en tres etapas, que su combustión al utilizarse como cobertura sobre el acero líquido genera pérdidas de masa aproximadamente del 81 %. La ubicación de las cavidades de contracción en los alimentadores de las piezas fundidas, se realizó mediante el corte longitudinal del sistema pieza-alimentador. El aumento de la capa de cobertura de cáscara de arroz influyó positivamente sobre la concentración de dichas cavidades en la superficie superior y la eficiencia de los alimentadores.

1-Introduction

Foundry is the oldest and most widely used method for producing metal parts. It is the only method that allows for the casting parts production of complex configurations in a wide range of weights, including its versatility and the possibility of recycling scrap, which cannot be done in any other process. Its constant improvement and development have made the foundry one of the most important production processes to promote industrial and economic development.

Due to the volume reduction that occurs in steel during solidification, an internal cavity is generated due to this shrinkage [1]. This change in volume must be compensated during solidification; otherwise, shrinkage defects may occur in a casting, making it unusable for its stated purpose [2]. This issue is addressed by incorporating a feeder in the mold, which acts as a reservoir of liquid steel that flows into the part as it cools and solidifies. The primary drawback of this approach is the need for an additional amount of liquid steel, as natural sand feeders can provide up to 14 % of their volume in liquid steel to plate-type casting parts and approximately 10 % to the chunkier or cylinder-type [1]. This leads to a decrease in the efficiency of the steel casting process by reducing the number of parts produced per cast.

To minimize the required amount of liquid steel for producing sound castings, exothermic and isothermic materials are used in sleeve form and hot topping to extend the solidification time, or modulus M, of risers. This method allows for direct solidification towards the risers and reduces their size [1-4]. Feeder sleeves have been the subject of research for many years, resulting in patented material formulations for this specific application [5].

At present, there is a significant advancement in these products, with readily available riser sleeves being well-established tools worldwide to reduce foundry costs. Approximately 80% of all steel castings are made using riser sleeves. The steel foundry industry in the United States spends $38 million annually on feeder sleeves [6, 7].

Hot top, hot topping materials, or anti-piping compounds (APC) are used in conjunction with riser sleeves. Hot topping materials have also seen significant development [3]. Hot toppings were probably the first type of feeding aid. Hot toppings materials are added to the tops of open risers after metal pouring to prevent radiant heat loss and provide additional insulation or heat to the riser surface. Insulating hot toppings consist of materials such as dry silica sand, rice husks or expanded perlite or vermiculite that have low density and excellent insulating properties. Exothermic materials can also serve as hot toppings. These typically rely on the thermite reaction, represented in the equation 1, as the heat source [8]:

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe + \Delta H_R = 851\ kJ \qquad (1)$$

Thermite has a specific heat of 3.977 kJ/g and can be used alone or mixed with an insulating material. It provides heat and insulation and is a source of liquid iron to provide additional feed metal into the riser. While there are a number of different hot topping formulations and types, their use has been somewhat problematic because of their physical form. Most hot topping materials are granular or powder; placing them accurately and safely on top of liquid metal in open risers is often difficult. A recent development addresses those issues. Floating Cover Lids (FCLs) have been designed as a replacement for traditional powdered hot top materials. ASK Chemicals L.P. has developed a line of this product to avoid the risks of traditional hot top material placement. It consists of a body produced with both insulating and/or exothermic refractory properties. The FCLs are made from a Low-Density Aluminum Silicate Ceramic (LDASC) material and are bonded with a phenolic urethane cold box (PUCB) resin system. They are made in round disk shapes, which are sized to fit inside traditional round open-top sleeve risers. Other shapes can be made as needed for other riser shapes to cover the liquid metal inside completely. The use of FCLs can dramatically improve the consistency of a riser's feeding efficiency. Many foundry variables are eliminated when FCLs are used, such as: how much topping was used, when it was applied, and did it really cover the riser evenly [8]. Ashland Casting Solutions developed a variant of insulating and exothermic FCLs. Which consists of an LDASC material for use in its line of EXACTCAST® riser sleeves, core, and mold components. The current line of EXACTCAST FCL ranges in sizes that fit risers from 3 to 22 inches diameter [9]. FOSeCO® has developed the THERMOXO, an exothermic powder, which reacts on contact with the feeder metal to produce liquid iron at a temperature of about 2000 °C, according to Equation (1). The product is intended for emergencies when there is a shortage of metal [10].

Rice husks (RH), along with other agro-industrial by-products, have been the focus of various research efforts, leading to different applications. The physical properties and chemical composition of RH can vary across different publications. The organic component of RH consists mainly of cellulose (28-36 %), hemicellulose (≈12 %), lignin (9-20 %), and pentose (21-22 %) [11], making up approximately 80 % of its organic biomass. On the other hand, the inorganic components make up about 20 %, with silica (SiO2) accounting for around 90 % of this portion. The physical properties of RH determine its suitability for specific industrial uses, such as its low thermal conductivity of 3.024 R-per-inch, comparable to high-quality insulating materials, and its high incineration temperature, which enhances its fire-resistant properties [12].

The key technical aspect for a biological material to be considered as a fuel is primarily determined by its elemental composition, including carbon, hydrogen, oxygen, nitrogen, sulfur, chlorine, and water. The elemental composition of RH samples from Canada, the United States (California), and China falls within the following ranges: carbon between 37.6 and 42.6 %; hydrogen between 4.7 and 5.78 %; oxygen between 31.37 and 37.62 %; nitrogen between 0.38 and 1.88 %; sulfur between 0.01 and 0.18 % and ash between 16.93 and 24.6 % [13]. There are also variations in the caloric value of RH. When considering the organic compounds and their respective caloric values, RH has fluctuating values ranging from 13.24 to 14.22 MJ/kg [13, 14]. Some studies propose that the caloric value of RH per dry mass ranges between 13.9 and 16.2 MJ/kg. [15]. These variations are attributed to different ash content and impurities produced by the oily film of aleurone. The moisture content of RH is another explored aspect, with similar values reported in other publications. The significant presence of opaline silica on the external surface of RH hinders the atmospheric moisture transfer into the hull. Approximately 2.1 to 6 % of the RH comprises a biopolyester known as cutin, which, in conjunction with a wax produced by the rice plant, creates a highly impermeable shield safeguarding the rice kernel from water and high humidity typically associated with rice cultivation and growth. Consequently, research conducted on RH at 25 °C reveals that the equilibrium moisture content of rice husk at 50 % relative humidity is at or below 10 %. Conversely, at 90 % relative humidity, the equilibrium moisture content of RH remains at or below 15 % [12]. In its dry state, RH absorbs water until its water content reaches equilibrium with the relative humidity of the surrounding air. For relative humidity values of 40 %, 60 %, 80 %, and 90 % in the surrounding air, the corresponding RH water content is 8.0 %, 10.5 %, 12.2 %, and 14.6 % respectively.

The caloric power of RH is related to its moisture content and decreases as the moisture content increases, with values ranging from 19880 kJ/kg (completely dry) up to 6413 kJ/kg (with 60 % moisture). For most energy conversion processes, it is crucial for the biomass must have a moisture content below 30 % [13]. This characteristic disqualifies RH as an ordinary or classic fuel, and it is not advantageous to use it as a power source [16] without requiring mechanisms to accelerate optimal combustion [13].

This biomass has a significant hydrocarbon content of 44 % [17], allowing it to be used as a fuel to generate the necessary heat, with a fuel value ranging from 3000 to 3600 kcal/kg. The fuel value represents the number of calories produced by the material [18]. In addition to the variation of the RH calorific value mentioned earlier, other authors report a value of 15.84 MJ/kg. Due to its high calorific value, it is considered a source of renewable energy source [19]. As emphasized in a recent study [20], this value represents a significantly higher heat input compared to commercial exothermic sleeves studied (2257–1857 kJ/kg) [21], as cited in other works [7].

Furthermore, its value as a fuel enables the definition of the RH as an exothermic material [19, 22]. It is an eco-friendly product with very low emissions [23], a criterion confirmed by its application in the steel casting parts process [24]. When RH is used as a hot topping, it burns at the high temperatures of steel in a liquid state, appreciating that CO_2 content decreases by increasing the values of H_2, CO, and CH_4 present in the volatile compounds [13, 14]. The evolution of gaseous compounds can represent more than 70 to 80 % by volume at high temperatures [13].

RH has a high ash content, compared to other combustible biomass, of approximately 20 % [13, 25]. The refractory nature of Rice Husk Ash (RHA) depends on its low content of alkali oxides [13]; some research reports a RHA's melting point of 1500 °C [14, 26]; while other authors suggest it can withstand temperatures up to 1600 °C [18]. The chemical composition of RHA varies widely, influenced by the rice plant's growth conditions and factors during combustion process. For example, one study reported a content of SiO_2 (91.42 %), K_2O (3.71 %), CaO (3.21 %), Al_2O_3 (0.78 %), and trace amounts of other oxides in the RHA [27] all of which can serve as insulators [20]. Some researchers attribute the high-heat insulating potential of RHA to its amorphous silica structure and high porosity [28, 29]. The significant contents of SiO_2 in RH makes this waste a valuable source of silica for various practical uses [30]. Depending on the temperature range and combustion duration, either crystalline or amorphous forms of silica can be obtained [31, 32]. Additionally, RHA is known to possess anti-piping properties among carbonaceous materials [20, 33].

Silica (SiO_2), also known as silicon dioxide, exists in two forms: amorphous and crystalline, each with different properties [34]. Research has shown that the temperature interval and combustion duration determine whether crystalline or amorphous silica is obtained [31, 32]. It is widely accepted that amorphous silica forms significantly in the range of 600 to 800 °C, while crystalline silica forms above 900 °C [31]. Previous research has demonstrated the significantly positive impact of using RH waste as a hot topping during the casting of carbon steel parts [20, 33, 35].

To validate the use of RH from the "Sur del Jíbaro" Agro-industrial Complex (Sancti Spíritus, Cuba) as heat-insulating covering material, its characterization and the ashes from its combustion was made, as well as, studied the effect of this Rice Husks Hot Topping Layer Height (RHHTLH) and Feeder height (FH) on the Feeding Safety Margin (FSM).

2-Materials and methods

2.1-Materials

In some experiments, a RH from the Complejo Agro-industrial Arrocero "Sur del Jíbaro" (Sancti Spíritus, Cuba), was used. This RH was obtained from the RH removal process and used in its raw, unprocessed form. Table 1 displays the chemical-physical characteristics of this RH used as a hot topping [36]. Additionally, it is noted that for over 20 different varieties of RH, the hydrogen content ranges between 4 and 5 % [15]. Other studies on RH produced in Cuba have reported hydrogen contents of 5.2 [37] and 5.6 % [38].

Table 1. Components and caloric power of the RH used in the experiments

TS (%)*	VS (%)	Ash (%)	L (%)	C (%)	H (%)	O (%)	N (%)	S (%)	$HCV_{d.b.}$ (MJ/kg)	$LCV_{b\ s.}$ (MJ/kg)
89.23	77.78	22.5	18.89	37.72	N.D.	33.7	0.38	0.097	16.5	15.2

* TS- Total solids, VS- Volatile solids, L- Lignin, $PCS_{b\ s}$ - Higher caloric value dry basis and $LCV_{d.\ b}$ - Lower caloric value on a dry basis.

When the RH undergoes a calcination process, it results in ash formation ranging from 13 to 29 % of its initial weight. The ash is primarily composed of silica, with a content varying between 87 and 97 %, along with inorganic salt contents [34]. Two methods were employed to obtain the RHA, allowing for the assessment of the combustion temperature's impact. The first method involved collecting samples of the hot topping RHA (CCA I and II), obtained from the sudden thermal shock at RH combustion temperatures near the pouring temperature of AISI 1045 steel. The second method included heating the RH in an electric oven at a rate of 10 °C/min, exposing it to 950 °C for 1 h (CCA 950). Subsequently, RH was cooled inside the furnace until reaching room temperature.

To assess the mass loss from RH combustion as hot topping, samples were first sieved and weighed before being placed on freshly poured steel. The resulting ash was then collected, sieved, and weighed. A volume of 6008 cm3 was used in each case, contained within a steel ring with an inside diameter of 300 mm and a height of 58 mm. The ring was lined with paper to hold the sieved RH, which was manually adjusted to be level with the top edge of the ring (see Figure 1A).

Figure 1 A, B, and C: Ring with the RH sample prepared to be placed on the newly poured steel, combustion of the RH sample on the AISI 1045 steel, resulting in RHA from the combustion.

2.2-Experimental plan

In order to assess the effect of RHHTLH on the efficiency of the riser feeder and the production of quality parts, an experimental plan was conducted. It involved casting cylindrical specimens of AISI 1045 steel with a diameter and height of 90 mm. It was determined that the natural feeder for these specimens should have a diameter of 115 mm and a height of 100 mm. The experimental design included varying levels of Feeder Height (FH) as outlined in Table 2. Each mold contained four specimens with a constant FH. The specimens were labeled from zero for the specimen without hot topping, to 3 based on the applied

RHHTLH (Table 2). The steel used in the experiment was processed in a 6-t electric arc furnace lined with basic firebricks. The molds were filled using a 1000 kg bottom-pouring ladle. The pouring temperature was set between 1600 and 1580 °C to maximize steel shrinkage. The RH was weighed based on the volume corresponding to the dimensions of the cavity over the feeder, where the RHHTLH was positioned. To ensure precise placement of the hot topping layer, pre-weighed RH was packaged in paper envelopes.

The castings (part and feeder) were sectioned longitudinally through machining to determine the FSM, which indicates the distance between the cavity contraction bottom and the part-feeder interface line. The FSM were then measured using a Vernier caliper.

Table 2. Experimental runs performed

Run	Feeder height (mm)	Hot topping layer height (mm)	Feeding Safety margin (mm)
1	25	0	-33
2	25	25	-32
3	25	50	-30
4	25	75	-20
5	50	0	-22
6	50	25	-7
7	50	50	2
8	50	75	10
9	75	0	-9
10	75	25	12
11	75	50	18
12	75	75	40
13	100	0	12
14	100	25	24
15	100	50	35
16	100	75	41

2.3-Use of XRD and TGA in the characterization of RH and RHA

The composition of the RH and RHA was determined using X-ray diffraction (XRD) in a D8 Advance axs diffractometer (Bruker, Germany), with λ Cu Kα radiation (1.5418 Ǻ) in an angular range of 2θ between 10° and 80°. The International Center for Diffraction Data (ICDD) charts were used to identify the phases present in the diffractograms.

To analyze the mass loss during RH pyrolysis and combustion, Thermo-Gravimetric Analysis (TGA) was conducted, along with its derivative (DTGA). The TGA tests were performed on a TGA Q50 V20.7 Build 32 equipment (TA Instruments). Additionally, the mass loss during RH combustion in contact with liquid steel and exchange with the medium was assessed. The weighing of the RH samples and the resulting RHA was carried out using a technical balance model metripond MÉRLEGGYÁR, class (III) with a capacity of 10 kg, manufactured in Hungary.

3-Results and Discussion

3.1-RH and RHA characterization

The diffractograms of two RH samples (Figure 2 I and II) exhibit similar patterns. These are notable for the intensity of peaks at angular values of 2θ: 14.79 °; 17.40 °; 22.40 °; 35.34 °; 42.09 °; and 45.86 °, a roentgenometric characteristic attributable of the "silica-cellulosic membrane" structure with a high degree of reticular disorder. Specifically, the peaks with the highest intensity were assigned to cellulose and silica. Cellulose possesses a crystalline structure, while hemicellulose and lignin (components of RH) are amorphous in nature [23], which explains why they are not represented in the diffraction patterns. The crystalline structure of cellulose is a result of hydrogen bond interactions and van der Waals forces between adjacent molecules [39]. Furthermore, various studies have documented the presence of low crystallinity silica in RH from different latitudes [40]. Moreover, this phase in RH has been observed upon heating RH to temperatures of 500 °C [41].

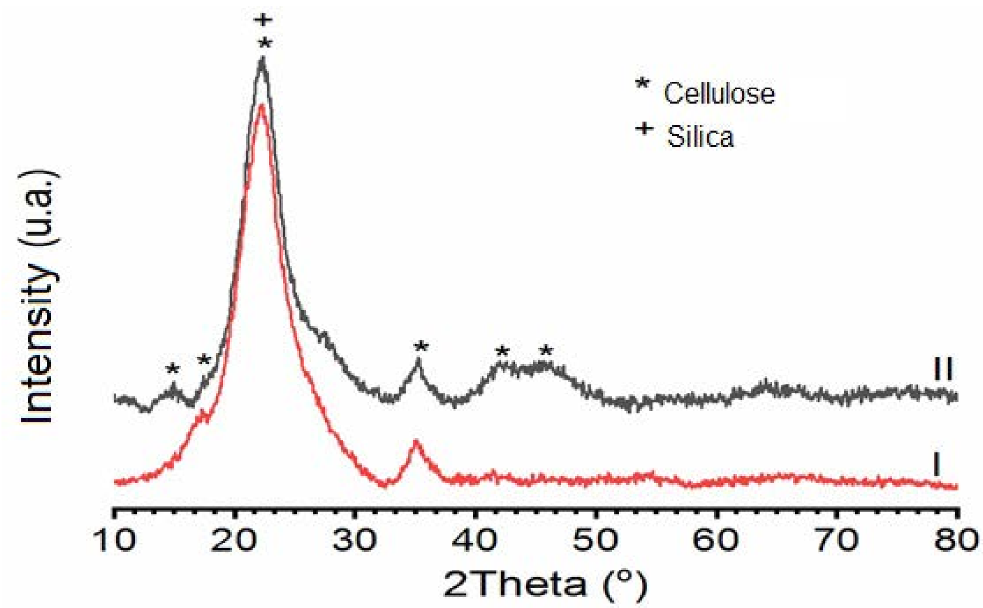

Figure 2. X-ray diffractograms of two samples of the rice husk (I and II) used as hot topping.

Figure 3 depicts the TGA and DTGA results for a RH sample. A detailed analysis of the RH thermal decomposition profile shows that its mass loss occurs in three stages. The first stage (between 20 and 45 °C) is attributed to the loss of moisture and light volatile products. When analyzing the corresponding DTGA curve, a peak around 50 °C is observed, which is consistent with other [42]. The second stage occurs between 180 and 370 °C and corresponds to the loss of highly volatile material. In this temperature range, the main constituents of RH decompose in an overlapping manner: hemicellulose, cellulose, and lignin. This phenomenon is evident in the DTGA curve, which initially shows a shoulder and then a peak related to the decomposition processes of cellulose and lignin, indicating active pyrolysis [43]. Finally, in the third stage (between 380 and 895 °C), the combustible material is burned. In the DTGA, no peaks are observed, and the TGA slope is smooth. This stage is associated with lignin decomposition, while the pyrolysis process can be partly attributed to carbon degradation reactions. The increase in temperature leads to a gradual thermal degradation of the lignocellulosic components of RH, including the elimination of moisture and very light volatile components, hemicellulose degradation, lignin and cellulose decomposition, and lignin degradation [42].

In general, the observed profile of the RH thermal decomposition, characterized by three stages, corresponds to the reports of different research [44, 45]. However, only two peaks were observed in the DTGA, whereas [42] additionally, a third peak was found at 469 ° C, and in a previous investigation, they only found one peak [46]. These differences could be related to the RH composition, specifically its alkali oxide content. On the other hand, other authors describe the first and third stages as endothermic, while they relate the second stage with an exothermic behavior [44, 45].

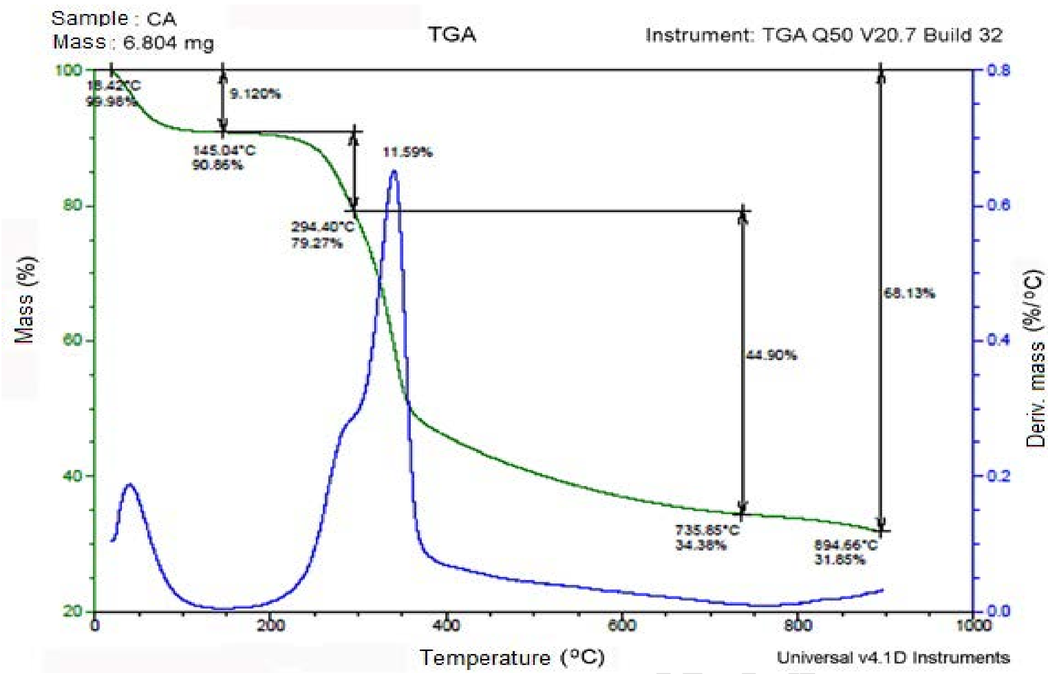

Figure 3. TGA (green) and DTGA (blue) curves of thermal decomposition of RH.

In diffractograms of Figure 4, it is observed that the fundamental phase of the hot topping RHA (ash of rice husks samples CCA I and CCA II), obtained by thermal shock (> 1540 °C), is fundamentally constituted by crystalline cristobalite, characterized by the presence of the peaks at 2θ: 21.94 °; 28.39 °; 31.36 °; 36.05 °; 46.91 ° and 48.52 °, among others. The presence of alkaline cations in the RHA contributes to stabilizing the presence of the tridymite polymorph, which can grow together with the cristobalite crystals and is identified by its most intense peak at 2θ 20.62 °, although the present peak was also assigned to this phase at 21.62 °.

Furthermore, the peaks observed at 2θ: 20.83 ° were assigned to quartz; 26.62 °; 39.54 °; 49.75 °; 50.10 ° and 59.89 °. Additionally, the presence of graphite is considered possible at 2θ: 26.54 ° and 44.51 °. The diffractograms of the RHA generated by combustion in a furnace, at temperatures up to 950 ° C (Figure 4 CCA 950), presents a broad peak limited in an interval between 15 ° and 30 °, indicating low crystallinity. In the diffraction pattern, the presence of cristobalite is identified at 2θ 21.80, 35.88, and 53.95 °. Different studies report the dependence of the phase composition of RHA on the combustion temperature, as well as the crystallinity of its phases [30]. When RH burns at temperatures below 500 °C, the formation of amorphous silica (SiO_2) or with low crystallinity is reported. At higher temperatures, the quartz turns into cristobalite and then tridymite [41]. In this sense, the presence of cristobalite and tridymite is reported in the ash of a RH burned to 1000 °C [41]. Furthermore, when using RH combustion temperatures of 1000 °C or higher, crystalline phases are obtain in its ash. In general, it has been found that at high combustion temperatures, cristobalite is resulting as the main phase and peaks with less intensity of tridymite in the diffraction patterns of RHA, although some authors also describe quartz peaks [47]. This behavior makes the advantage of heat in the risers possible and, consequently, increases the efficiency of the steel casting parts process.

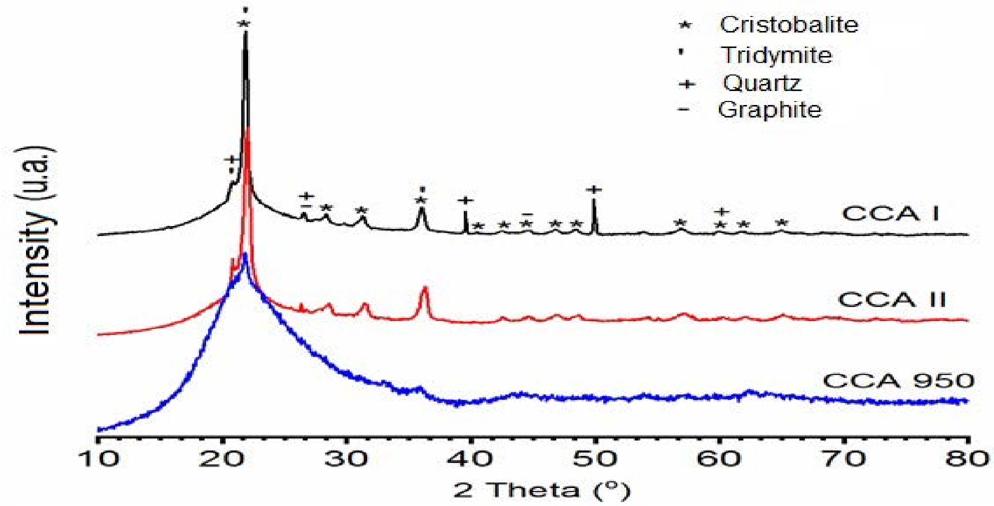

Figure 4. X-ray diffractograms of the RH ash obtained at different combustion temperatures. CCA II and I close to the pouring temperature. CCA 950 at temperatures up to 950.

3.2-Loss of RH mass during use as hot topping

Table 3 displays the findings of the combustion test of RH samples in contact with the liquid steel as depicted in Figure 1. When the RH comes into contact with the liquid steel at a temperature close to the steel pouring into the molds, it triggers a thermal shock with highly energetic pyrolysis and combustion, resulting in the formation of a silica layer that thermally insulates the metal. Initially, there is an evident energy release, indicating that the RH functions as an exothermic material. The percentage of RHA obtained in this study (Table 3), relative to the initial weight of the RH, aligns with the range reported in a referenced research study [34]. This combustion process of RH led to an average mass loss of 80.27%, a value higher than the 68.13% observed in the TGA, attributed to the elevated temperature of the combustion processes.

Table 3. Results of the RH combustion test during its use as a hot topping

Experimental run	RH mass (g)	RHA mass (g)	Mass lost (%)
1	990	200	79.80
2	1100	200	81.82
3	1180	220	81.36
4	1050	230	78.10
Average			**80.27**
Standard deviation			**1.45**

3.3-Influence of RHHTLH and FH on the efficiency of the riser

Figure 5 illustrates the effect of the variables RHHTLH and RH on the positioning of the contraction cavities within the system consisting of cylindrical AISI 1045 steel parts specimens and their feeders. The zero line denotes the part-feeder interface. As per Table 2, in Figure 5, the first number below the specimen indicates the FH, and the second indicates the applied RHHTLH.

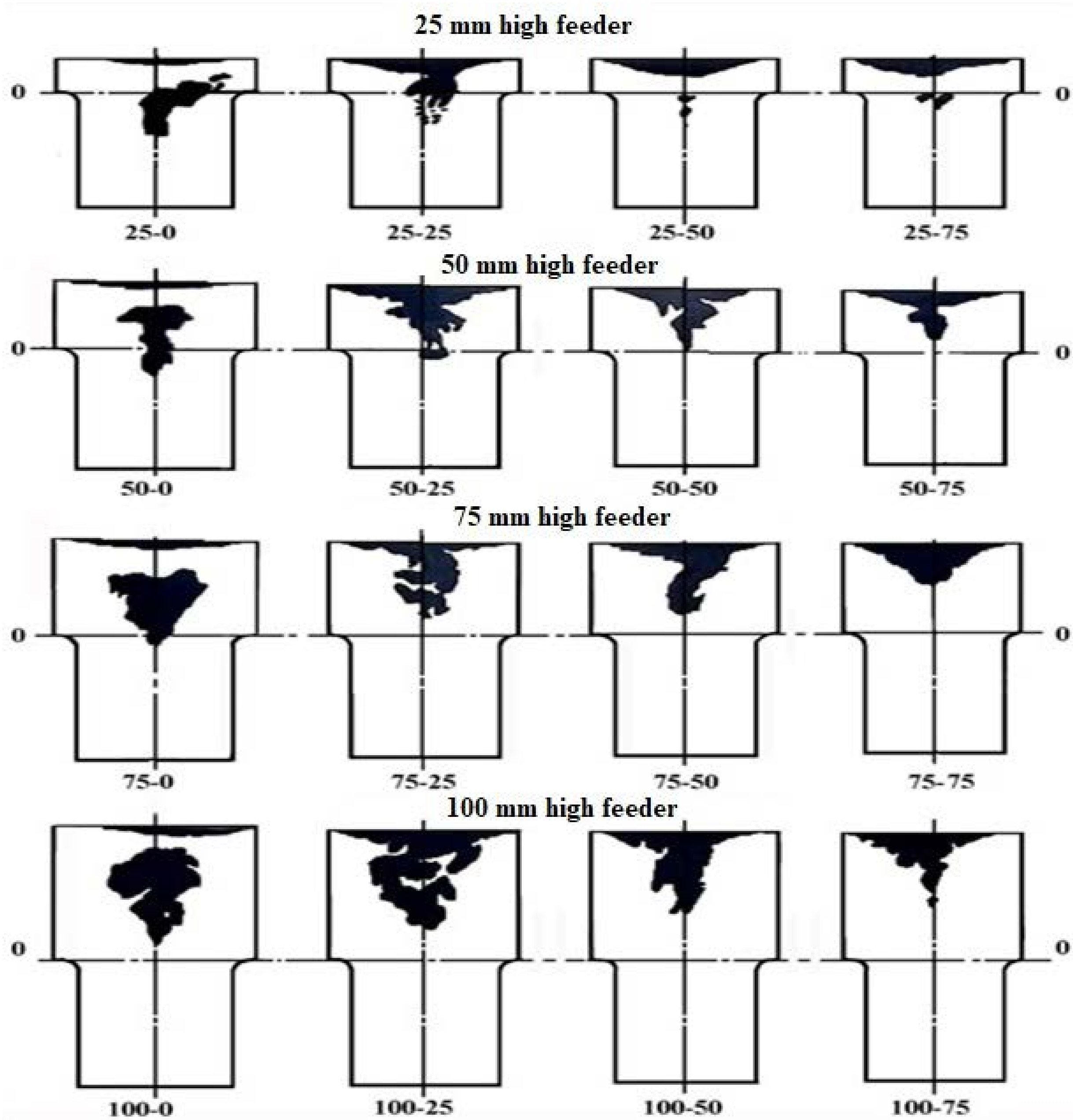

Figure 5. Schematic representation of contraction cavity location as a function of the RHHTLH and the FH.

The effect of increasing FH is reflected in the enhancement of the FSM, peaking for the calculated feeder of 100 mm in height (Table 2 and Figure 5). It is evident that, irrespective of the applied RHHTLH, the volumetric behavior of the 25 mm FH was insufficient to produce defect-free parts specimens (Figure 5). With the increase in RHHTLH, the contraction cavities tend to concentrate more in the center and on the upper surface of the feeder. This trend is attributed to the rise in modulus (solidification time) resulting from an increase in this variable. When using 50 mm FH with 50 and 75 mm RHHTLH, the feeder became volumetrically sufficient to obtain sound specimens, increasing the metallic efficiency of the system, which shows a FSM between 2 and 10 mm, respectively. In the first case, the value of the feeding safety margin is lower, and in the second, it is similar to the 12 mm, obtained in the reference experiment (100 mm high feeder without RHHTLH). This is due to the greater volumetric availability of this feeder but with more significant metallic inefficiency to deliver up to 10 % of its volume to the part. In the 75 mm FH, the specimens show a FSM similar to or greater than that presented by the 100 mm FH without RHHTLH. Additionally, when combining RHHTLH with 75 and 100 mm FH, sound specimens are obtained in all evaluated variants with a wide FSM (Figure 5). In general, the results show that the RHHTLH has a significantly positive effect on the soundness of AISI 1045 steel cylinder-type parts. Furthermore, they indicate that the application and the correct placement of RHHTLH on the feeders increase the metallic efficiency in AISI 1045 steel casting parts and thus reduce production costs.

From the experimental results obtained (Table 2), the Hot Topping factor *y*, Apparent Surface Alteration Factor (ASAF) was determined using the L. Plutshack method [48], which is associated with the heat retention effect by shielding the radiation from RHHTLH. Understanding the ASAF of the feeding aid materials used is crucial for calculating assisted feeders with exothermic or isothermic materials. The ASAF coefficients are dimensionless, ranging from 0 to 1; the closer the value is to 0, the more effective the feeding aid material is [3]. For RHHTLH of 75 mm and 50 mm, the ASAF (*y*) was calculated using Equation 2 with *x* set to 1 for sand contact [3], resulting in values of 0.75 and 0.5, with a mean value of 0.6.

$$M'_r = \frac{H \times D}{4 \times H_x + D_y} \qquad (2)$$

Where: M'_r represents the apparent riser modulus in cm. *H* denotes the RH in cm. *D* indicates the riser diameter in cm. *x* is the sleeve ASAF. *y* is the Hot Topping ASAF.

Based on the independent variables of the experimental plan and the FSM results (Table 2), statistical processing was conducted using the Stratigraphy's software, resulting in the model (equation 3) with a high fit (R^2 adjusted for g. d.) = 95.52 %). At a confidence level of 95 %, both independent variables exhibit a significant impact, while at a confidence level of 90 %, the two variables show significance; along with the interaction of these (P=0.0695) and the square of the FH (P=0.0542). Given the technological nature of this process, it is appropriate to consider a confidence level of 90 %. Additionally, a response surface graph is generated for the FSM (Figure 6), illustrating that an increase in both independent variables leads to an increase in the FSM.

$$FSM = -66{,}425 + 1{,}2151 \times RH + 0{,}2005 \times RHHTLH - 0{,}0047 \times RH^2 + 0{,}003504 \times RH \times RHHTLH - 0{,}0003 \times RHHTLH^2 \qquad (3)$$

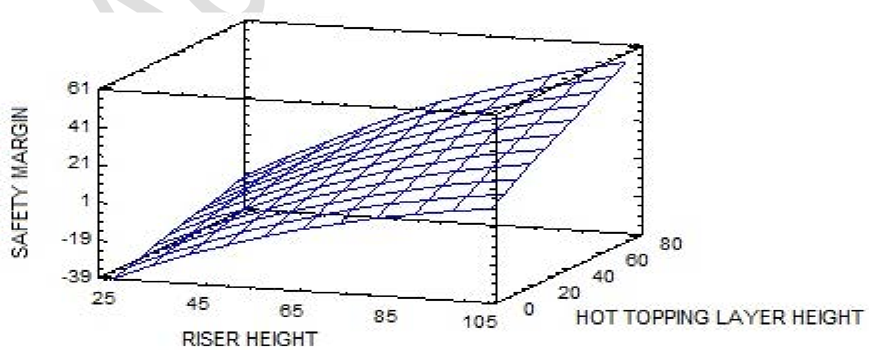

Figure 6. Response surface of FSM, as a function of FH and RHHTLH

The results obtained when using RH as a hot topping material in steel casting parts are due to the fact that, during its combustion, it behaves like an exothermic material. In addition to its high ash content, it also has refractory and heat-insulating properties. At high temperatures, it acts as a fuel due to its caloric power (Table 1), which is delivered in the exothermic reaction that characterizes its pyrolysis and combustion in contact with the steel in a liquid phase [44, 45]. After combustion, it acts as an insulating material, forming an ash cover with a high silica content. Due to its dimensional stability, a highly porous, three-dimensionally branched silica barrier [49], which completely shuts off radiation heat transfer and slows down the convection heat transfer process at a very low rate, during the time the feeder delivers liquid steel to the part.
The complex behavior presented by the RH when it is used as a hot topping in the steel feeders is due, among other aspects, to the transport mechanisms and transformations that silicon undergoes in the rice plants. Silicon penetrates the plant in a soluble form, probably as a silicate or a mono-silicic acid, then moves towards its outer surface, where it is concentrated by evaporation and polymerization, to form a "silicic-cellulosic" membrane in the RH without lattice, atomic or molecular order [11, 49]. When the RH is poured onto the steel surface in a liquid state, it dehydrates, volatilizes almost instantly, and vigorously burns all organic compounds, resulting in a porous micro-skeleton of amorphous silica in a highly viscous solid-liquid state (similar to common glass) for each shell. This forms a refractory and porous layer on the feeder, consisting of a material with a high silica content (approximately 90 %) [14, 26]. At lower temperatures, silica forms crystalline structures, including cristobalite and tridymite. The high silica content in the form of these compounds in the ash layer, along with its high porosity, low apparent density, and excellent refractoriness, contribute to the efficient shielding effect against heat transfer by radiation and convection during the solidification process of the part-feeder system.

The heat retention effect of the feeder, preventing energy loss by radiation due to the characteristics of the RHA, significantly influences the final outcomes. By preserving this energy, the steel remains in a liquid state, while the pressure from the metal-static column in the feeder supports the part throughout its solidification period. This enables the feeder to operate more efficiently, ensuring excellent integrity of the part by focusing the cavity contraction of the part-feeder system on the upper surface and the feeder center.

Among the various biomasses studied, RH has the highest ash content [12, 13, 37], making it suitable for use as a hot topping in the casting of carbon steel parts due to its favorable physical-chemical characteristics. These attributes are advantageous when RH is used as an "exo-isothermic (refractory)" material, combining its capacity to carry energy at high temperatures with its heat-insulating and fire-retardant properties.

4-Conclusions

It was determined that the evaluated RH has about 20 % ash. In the TGA and DTGA tests, it was found that its thermal decomposition occurs in three stages. It was confirmed that the calcination temperature influences the phase composition of the RHA. In the ashes from the use of RH as hot tipping in the carbon steel casting parts, cristobalite and tridymite predominated, although the presence of quartz was also observed.

The RHHTLH showed an influence on the location of the cavities contraction in the AISI 1045 steel part-feeder system. When using higher RHHTLH, it was observed that cavities tend to appear only in the feeder. This behavior was evident in the feeders that had a FH of 50 and 75 mm. In these feeders, the specimens showed a FSM similar to or higher than that presented by the calculated feeder, used as a reference (100 mm high and without hot topping). It was observed that the FSM grows as the RH and the RHHTLH increase, indicating an improvement in the efficiency of the carbon steel casting parts process.

5-Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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8-Author contributions

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Lorenzo Perdomo González. State of the art review, data analysis 10 % of total work.

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9- Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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