



Research Article

Utilizing Gum Commiphora Mukul as Organic Binders to Replace Bentonite in Iron Ore Pelletizing

H. Koohestani ^{*1}, A. Balooch ², J. Hasanpoor ³*Department of Materials Science and Engineering, Semnan University, Semnan, Iran*

ARTICLE INFO

Keywords:

Green Steel, Gum Commiphora Mukul, Green Pellet, Pellet Making, Iron Making.

Article history:

Received 31 October 2024

Received in revised form 20 December 2024

Accepted 09 March 2025

ABSTRACT

The use of powdered concentrate in iron production reduces the furnace efficiency. As a result, the concentrate was converted into pellets. Bentonite is usually used as a binder in pellet production, posing several operational challenges in the kiln. Therefore, organic binders have been introduced as alternatives to bentonite and other mineral binders. This study investigates the application of Commiphora Mukul gum (GCM) for the production of hematite pellets. First, pellets were prepared using the GCM and bentonite binders. The mechanical properties of the heat-treated pellets were also evaluated at various temperatures. The results showed that pellets baked at 1200°C and bentonite-bonded pellets had a compressive strength of approximately 1000 N/pellet. Pellets bonded solely with GCM gum exhibited insufficient strength. The optimal binder comprising a mixture of 2% bentonite+3% GCM binder achieved a compressive strength of 900 N/pellet. Therefore, the organic binder GCM alone cannot provide sufficient strength, while its combination with bentonite yields superior results.

1. Introduction

After processing, the iron ore is converted into a powdered concentrate. Gas permeability within the blast furnace burden and direct reduction processes are significantly reduced due to the fine particle size of the concentrate, thereby impairing furnace performance. Pelletization is a common method to address this issue. Pellets are small spherical agglomerates produced from iron ore concentrate and various additives, such as binders

(bentonite, organic materials, lime, and cement) and water [1, 2].

Various methods can be used to produce pellets. The iron content of the pellets ranged from 67 to 69%. Different binders could be used to convert the iron concentrate into pellets during pelletizing. Bentonite is the most common binder which can have various compositions [3, 4]. With a general chemical formula of $(\text{Na}, \text{Ca}, \text{Mg})\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O}$, bentonite belongs to the group of aluminosilicate clay [5]. It primarily consists of 85% montmorillonite and silicate, which are detrimental for the steelmaking processes. The hygroscopic nature of bentonite can lead to pellet degradation. Its acidic properties can also damage refractory materials and adversely affect the alkaline conditions within the furnace [6, 7]. Alkaline compounds, such as lime, are added to counteract the acidic environment of the furnace, whose excessive amounts can, however, reduce the efficiency of the furnace. Consequently, a higher percentage of this

* Corresponding Author

Email: h.koohestani@semnan.ac.ir

Address: Department of Materials Science and Engineering, Semnan University, Semnan, Iran

1. Associate Professor, 2. M.S., 3. Ph. D. candidate

DOI: <http://10.22034/IJISSI.2025.2044698.1308>

Published by ISSI (Iron & Steel Society of Iran)

binder exacerbates pellet quality. Various alternatives to bentonite have been explored, including sodium silicate (water-glass). Unlike bentonite, this compound lacks metallic oxide components but still contains silicates. Extensive research has investigated the feasibility of replacing mineral binders with organic ones. For instance, carboxymethyl cellulose (CMC), starch, and plant gums are among the organic compounds that decompose at high temperatures without impurities [8-10].

Ultimately, pellets with an apparent diameter of 9-16 mm achieve a compressive strength of at least 1780 N/pellet after sintering to ensure their integrity during handling and subsequent operations [11, 12]. Throughout the pelletizing process, as part of quality control, pellets undergo mechanical strength tests at various stages. Common measurements include the drop test for green pellets, compressive strength tests for dry pellets, and compressive strength tests for fired pellets [11]. Results indicated that pellets bonded with a combination of 1% bentonite and 1% corn starch exhibited superior compressive strength, creep strength, and pellet test strength [13, 14].

A recent study explored the use of novel organic binders to minimize bentonite consumption. While reducing bentonite content leads to a decline in the metallurgical and physical properties of the pellets, the incorporation of organic binders can significantly improve these properties [15, 16].

Anand Babukota et al. [17] utilized molasses, a by-product of sugar production which is a thick syrup extracted from sugarcane or sugar beet, as a binder. The moisture absorption of pellets prepared with varying amounts of molasses was investigated. The moisture contents absorbed by binder-free pellets and those comprising bentonite and molasses were 7.72% to 9.95%, 9.62% to 10.84%, and 6.14% to 6.69%, respectively. The compressive strength of wet pellets containing molasses ranged from 43 to 230 N/pellet, superior to pellets containing bentonite with a strength range of 9.47 to 11.92 N/pellet. The compressive strength of dry molasses-modified pellets increased to 222-394 N/pellet, representing the highest value recorded for dry pellets to date.

In this research, gum from the Commiphora Mukul (GCM) tree, which is mainly found in the Indian

subcontinent, was used as a binder for the production of iron ore pellets. Although GCM is naturally adhesive, its inherent stickiness is insufficient for creating a strong and durable bond. Note that industrial adhesives typically contain specific chemical compositions which enables the formation of robust and long-lasting bonds.

2. Materials and Methods

Hematite iron ore was collected from the iron ore mines of Semnan Province, whose composition is presented in Table 1. Bentonite and gum Commiphora Mukul (GCM) were used as binders. Table 2. shows the chemical composition of bentonite.

To prepare the GCM gum binder, 100 g of gum was boiled in 900 mL distilled water for 1 h. Subsequently, the solution was filtered three times to remove suspended particles. The resulting solution was sprayed onto the materials during pelletizing.

Hematite powder with a particle size smaller than 65 μm was obtained using a jaw crusher and disc mill (Retsch GmbH, Vibratory Disc Mill RS 100) for 3 h. The pelletizing machine was a disc type with a diameter of 77 cm and a height of 16 cm. Initially, 500 g of fine powder was thoroughly mixed with 25 g of bentonite powder. The uniform mixture was added to the rotating disc. Water was sprayed onto the mixture on the rotating disc every 3–5 min to provide the moisture required for the formation of pellets. After sufficient growth of the pellets, they were removed from the machine and dried in ambient air for 24 hours. The wet pellets were then dried in an oven at 110°C for 1 h. The remaining pellets were prepared using 3% bentonite + 2% organic binder, 3% organic binder, and 5% organic binder. The pellets were heated at 900, 1000, and 1200°C according to the temperature program shown in Fig. 1. The samples were labeled as listed in Table 3.

To analyze the raw materials and final products, X-ray fluorescence spectroscopy (XRF-1800, Shimadzu, Japan), Fourier transform infrared spectroscopy (FTIR 8400S, Shimadzu, Japan), thermal analyzer model STA 6000 (PerkinElmer, USA), and X-ray diffractometer (XRD D8 Bruker, using Cu-K α radiation with a wavelength $\lambda=1.5406 \text{ \AA}$ filtered with nickel) were used.

Table 1. The chemical composition of iron concentrate.

%Fe ₂ O ₃	SiO ₂ %	Al ₂ O ₃ %	MgO%	CaO%	MnO%	Na ₂ O%	%SO ₃	L.O.I%
67.5	16.36	3.92	2.85	1.02	0.07	0.29	1.08	2.12

Table 2. The chemical composition of bentonite determined by XRF.

SiO ₂ %	Al ₂ O ₃ %	V ₂ O%	CaO%	MnO%	Na ₂ O%	%SO ₃	%Fe ₂ O ₃	%Other
63.4	21.1	1.85	1.20	0.13	2.31	0.44	3.22	7

Compression and drop tests were also conducted using a universal testing machine (STM 400, Santam, Iran) to investigate the mechanical properties of pellets. The drop number test records the maximum number of times green pellets remained intact after being dropped from a height of 0.5 m onto a steel plate. Each test was performed on 5 pellets, and the average results were reported.

3. Results and Discussions

According to the chemical composition of the ore

shown in Table 1. Fe_2O_3 has the highest percentage (67.5%) among the minerals. Al_2O_3 and SiO_2 were the most abundant impurities. The X-ray diffraction (XRD) analysis, shown in Fig. 2, also reveals the presence of hematite (Fe_2O_3) and goethite ($FeO(OH)$) in the ore. Additionally, quartz (SiO_2) and kaolinite impurities were detected [18].

Fourier Transform Infrared (FT-IR) spectroscopy was performed over the range of $400-4000\text{ cm}^{-1}$ to investigate the bond interactions in GCM and P5G. Based on Fig. 3. and Table 4. the characteristic peaks

Table 3. Details of different pellet binders.

Sample	P5B	P3B	P3G	P5G	P2B3G
Type of binder	5% bentonite	3% bentonite	3% gum	5% gum	2% bentonite + 3% gum

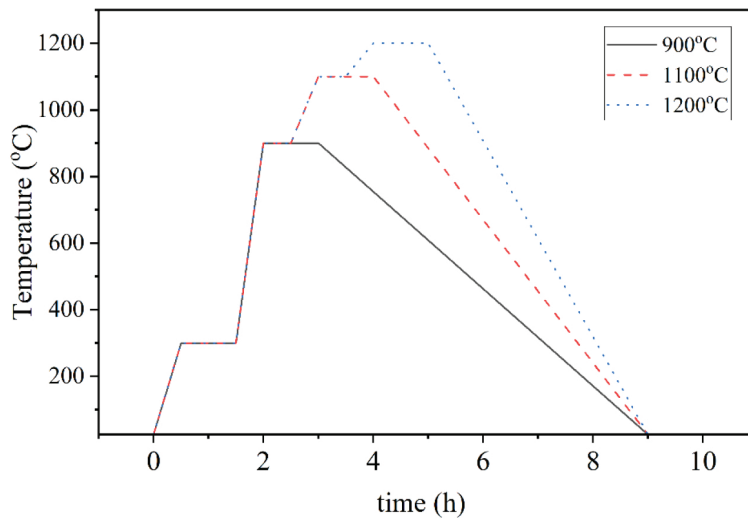


Fig. 1. Pellet sintering temperature schedule.

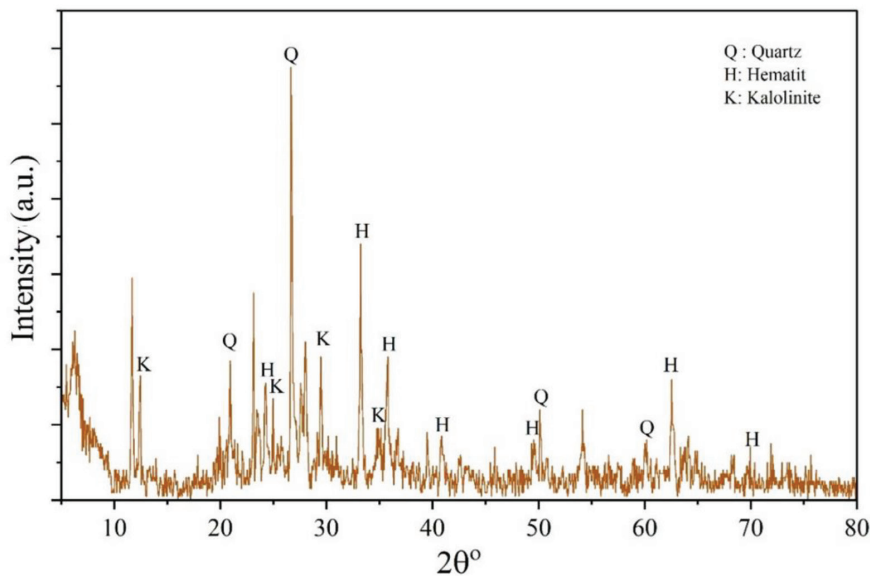


Fig. 2. X-ray diffraction analysis of iron powder.

in the spectrum include OH stretching vibrations at 3600-3200 cm^{-1} , C=O stretching vibrations at 1700-1600 cm^{-1} , C-O stretching modes at 1200-1000 cm^{-1} , and C-H bending vibrations at 800-600 cm^{-1} [19-21]. The electrostatic attraction, hydrogen bonding, and van der Waals forces are involved in the bonding between the iron ore and organic binder pellets. This iron ore-binder interaction is schematically shown in Fig. 4. When raw pellets are formed, moisture hydroxylates the surface of the ore particles, facilitating the dissolution and diffusion of organic molecules, and enhancing adhesion. With the rotation of the pelletizing device, the colloid adhered to the surface of the particles and continuously attached to the surrounding ore. Continuous rotation of the disc led to the pellet rotation and compaction. Upon gradual hardening, it finally formed a pellet with adequate strength [8]. In this mineral-organic binder system, electrostatic attraction was the strongest binding force. Fe-OH^{2+} is formed by absorbing H^+ from moisture [5, 22].

The carboxyl groups in the organic binder (HO-[P]-COOH) ionize to form HO-[P]-COO⁻ [23]. These groups possess opposite surface charges, creating electrostatic attraction. Further reactions led to the formation of

HO-P-OC-O-Fe [24]. Fe-O⁻ is formed by the adsorption of OH⁻ on the surface of iron ore; while the HO-[P]-COOH group combines with OH⁻ to form HO-[P]-COO⁻. Due to their similar charges, these compounds exhibit electrostatic repulsion [25, 26]. While electrostatic repulsion negatively affects the adsorption on the ore surface, organic compounds can form a strong molecular network, providing a strong adhesion force to improve the bond strength between mineral particles.

To address the issues associated with inorganic binders, organic binders such as starch have been proposed as alternatives. The organic content of these binders are eliminated from the green pellet structure during sintering. Fig. 5. shows the thermogravimetric analysis (TGA) of blue gum at 900°C in an air atmosphere. The first stage of weight loss occurred from room temperature to 313 °C, indicating the removal of water and impurities from the structure. The second stage of weight loss at 313-452°C corresponds to the decomposition of organic compounds; whereas the third stage, at temperatures above 452°C, shows minor weight changes related to the decomposition of residual compounds in the pellet. As a result, all organic compounds were eliminated.

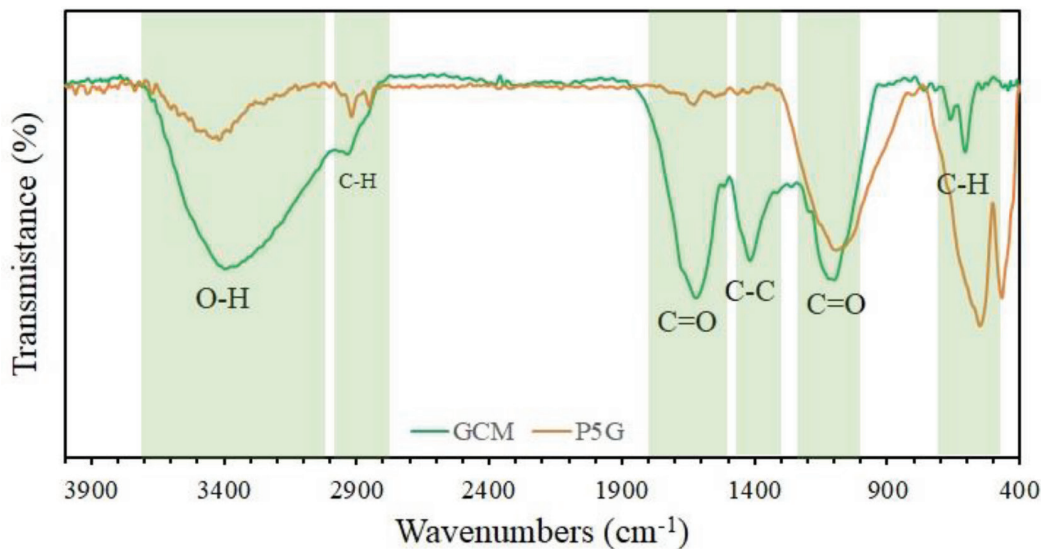


Fig. 3. Infrared Fourier transform spectroscopic analysis of the GCM and P5G.

Table 4. wavenumber and type of bond in GCM and P5G [27, 28].

Wavenumber (cm^{-1})	Type of bond	Bond
600	bending	C-H
1110	stretching	C-O
1416	stretching	C-C
1620	stretching	C=O
3404	stretching	O-H

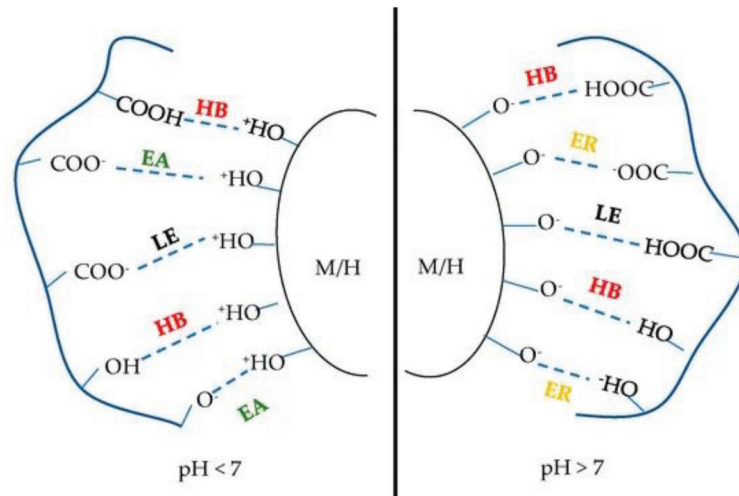


Fig. 4. Surface interactions between organic binders and the mineral phases magnetite (M) and hematite (H): HB, hydrogen bonding; EA, electrostatic attraction; ER, electrostatic repulsion; LE, ligand exchange [27].

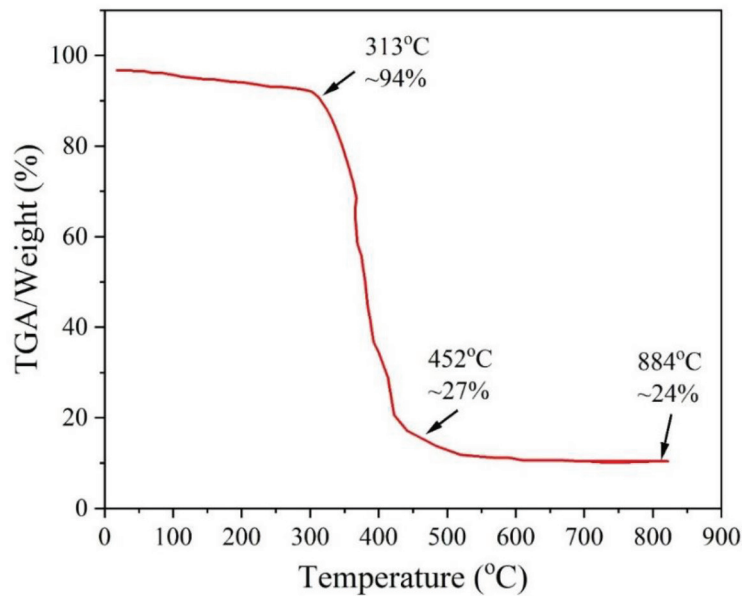


Fig. 5. Thermal calorimetry analysis of the pellets prepared with GCM.

Fig. 6. and Table 5. present the changes in the compressive strength of the pellets at various conditions. In the raw state, the compressive strength of the pellets with the bentonite binder was higher than that of the gum binder. The combined binder exhibited an acceptable strength. For all samples, temperature elevation led to a noticeable increase in the compressive strength. For example, the compressive strength of P5B grew from 9 N/pellet in the raw pellet state to 1000 N/pellet with increasing temperature to 1200 °C.

The pellets with 2% bentonite fired at 1200°C showed a compressive strength of 750 N/pellet [29]. The strength of pellets comprising both bentonite and gum was similar to that of P5B. However, the use of high levels of bentonite as a binder in pellets is not desirable as it acidifies the kiln environment [28]. The results showed that the

co-incorporation of gum and bentonite created favorable conditions for the pellet without eliminating bentonite. According to the results, the sample with a mixed binder can replace the pellets with bentonite. The kiln pH can be maintained at high levels by increasing the content of gum, hence, reducing the consumption of lime and bentonite. The strength achievable by adding high contents of binder is unnecessary; moreover, overconsumption of binder results in additional cost.

In dry pellets, the organic binder provides cohesive strength after hardening into a solid bridge [30]. Bentonite modification improves the compressive strength of dry pellets by forming mechanical bridges and films with binders at particle contact points [19]. The co-incorporation of calcined colemanite and organic binders increases the compressive strength of raw, preheated, and fired

pellets compared with bentonite-containing pellets [31]. The maximum compressive strengths of pellets preheated at 1000°C produced with organic binders were 106, 90, and 82 kg/pellet for 0.20% CMC, 0.05% Ciba DPEP06-0007, and 0.30% corn starch additives, respectively [28].

The significant decrease in the strength of the preheated pellet could be due to the burning of the organic binders at this temperature. The compressive strength of pellets baked at 1300°C produced with organic binders was reported to be as good as bentonite-bonded pellets. According to Ngara et al. [32], pellets indurated at 1200°C with carboxymethyl

cellulose (210 kg/pellet) and sodium lignosulfonate (198 kg/pellet) were weaker than bentonite pellets (250 kg/pellet), while meeting the industrial requirement of compressive strength (approximately 181 kg/pellet) [28].

Table 5. lists the drop test results at 1100°C, and Fig. 6. shows the trend of its changes. The more steps the sample passed, the higher its impact resistance. The P5B showed the highest impact resistance while the P2B3G and P3B exhibited similar results. The other samples with gum did not offer adequate resistance. Qiu et al. [30] reported the wet drop number and dry drop number of pellets with an organic binder as 6.7 and 16.2 times/1.0 m, respectively.

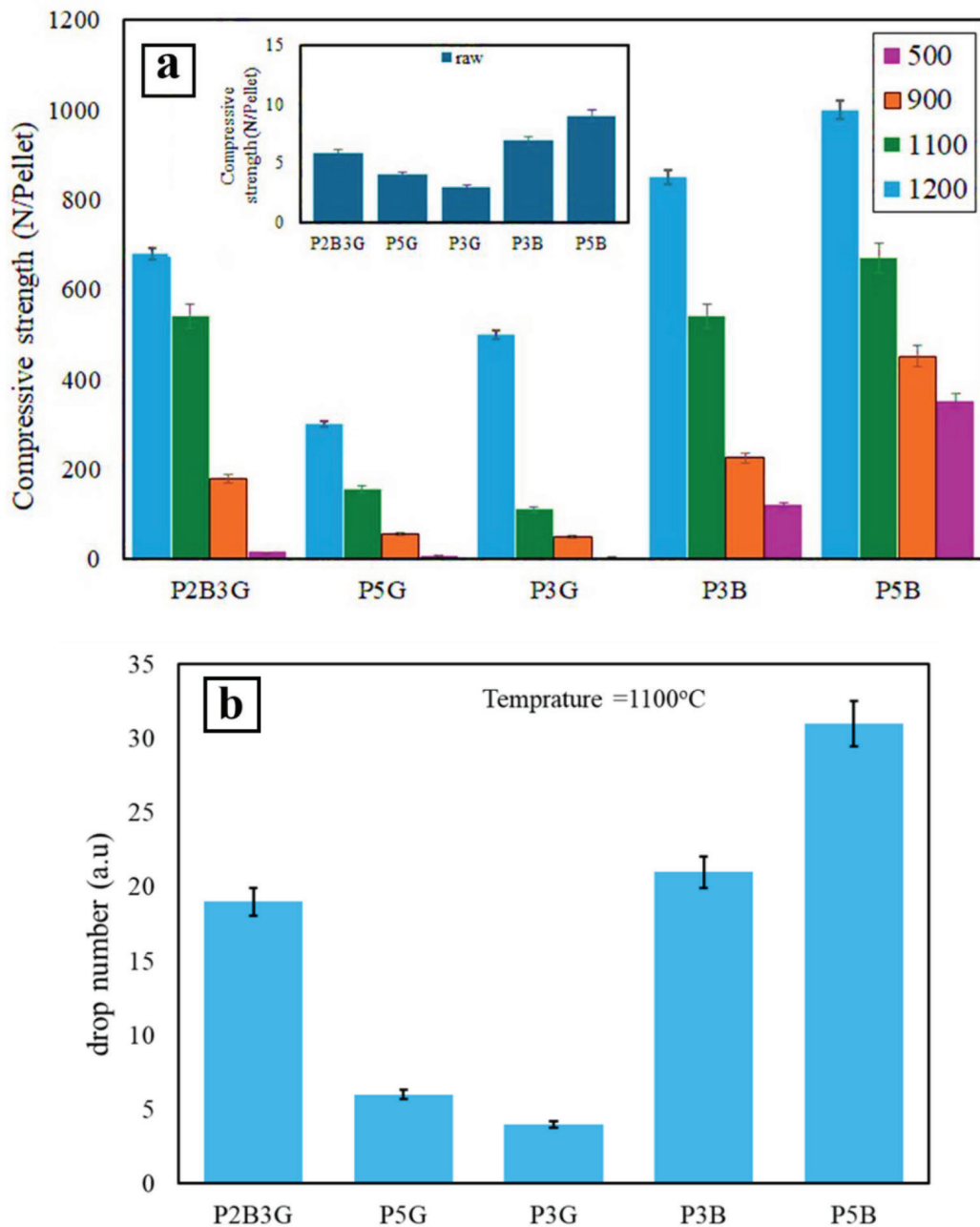


Fig. 6. (a) Variations in compressive strength of different pellets under different temperature conditions (N/pellet) and (b) results of drop strength of pellets.

Table 5. Compressive strength results (N/pellet) of pellets and drop test results of pellets sintered at 1200°C.

Sample	Sintering temperature (°C)					Step test in 1100°C (times/0.5m)
	1200	1100	900	500	Raw	
P5B	1000	670	452	350	9	30<
P3B	850	540	226	120	6.8	21
P3G	500	100	50	5	3.5	4
P5G	300	156	55	8	4	6
P2B3G	680	540	180	15	5.8	19

4. Conclusions

In this study, bentonite and water gum *Commiphora Mukul* were used as binders for pelletizing hematite iron concentrate. The pellets were sintered at different temperatures and then their mechanical properties were evaluated by compressive strength and drop number tests. Regarding the urgent need for the removal or reduction of bentonite to improve the performance of the blast furnace, plant gums can be a suitable candidate for pellet production because of their good adhesion. It has been shown that gum *Commiphora Mukul* alone cannot provide sufficient compressive strength. Its combination with bentonite, in addition to providing sufficient compressive strength to the pellets, will improve the efficiency of the iron production by reducing the consumption of bentonite.

References

- [1] Ball D.F, Agglomeration of iron ores. 1973.
- [2] Moraes S, Lima J, Ribeiro T, Iron Ore Pelletizing Process: An Overview. 2018.
- [3] Eisele T, Kawatra S, A review of binders in iron ore pelletization, *Miner Process Extr Metall Rev.* 2003; 24(1): 1-90.
- [4] Hasan U, Experimental study on bentonite stabilisation using construction waste and slag. Curtin University; 2015.
- [5] Koohestani H, Hasanpoor J, Ghasemi B, Eco-friendly steelmaking: Exploring the potential of plant-based binder Acacia gum for iron ore pelletizing, *Case Stud Chem Environ Eng.* 2025; 11: 101110.
- [6] Mourão J.M, Conceptual aspects concerning the pelletizing of iron ores. 2023.
- [7] Sandra Lúcia de M, José Renato Baptista de L, Tiago Ramos R, Iron Ore Pelletizing Process: An Overview, In: Volodymyr S, editor. *Iron Ores and Iron Oxide Materials*, Rijeka: IntechOpen. 2018; 3.
- [8] Sivrikaya O, Arol A.I, Alternative binders to bentonite for iron ore pelletizing-Part I: Effects on physical and mechanical properties, *Holos.* 2014; 3: 94-103.
- [9] Halt J.A, Kawatra S, Review of organic binders

for iron ore concentrate agglomeration, *Miner Metall Process.* 2014; 31: 73-94.

[10] De Moraes S.L, et al. Binding mechanism in green iron ore pellets with an organic binder, *Miner Process Extr Metall Rev.* 2020; 41(4): 247-254.

[11] Othman R, Sreekantan S, *Materials: Leading the Path of Engineers (Penerbit USM)*, Penerbit USM. 2012.

[12] Indra A, et al. Enhancing the physical and mechanical properties of pellet-shaped hydroxyapatite by controlling micron-and nano-sized powder ratios, *Ceram Int.* 2020; 46(10): 15882-15888.

[13] McDonald J.E.D, Kawatra S.K, Agglomeration of hematite concentrate by starches, *Miner Process Extr Metall Rev.* 2017; 38(1): 1-6.

[14] Zhao H, et al. A review on the effect of the mechanism of organic polymers on pellet properties for iron ore beneficiation, *Polymers.* 2022; 14(22): 4874.

[15] Ma Y, et al. Reducing bentonite usage in iron ore pelletization through a novel polymer-type binder: Impact on pellet induration and metallurgical properties, *J Mater Res Technol.* 2024; 30: 8019-8029.

[16] Lohmeier L, et al. Use of bentonite and organic binders in the briquetting of particulate residues from the Midrex process for improving the thermal stability and reducibility of the briquettes, *Steel Res Int.* 2021; 92.

[17] Kotta A.B, et al. Effect of molasses binder on the physical and mechanical properties of iron ore pellets, *Int J Miner Metall Mater.* 2019; 26(1): 41-51.

[18] Hassanjani-Roshan A, et al. Evaluation of the performance of polystyrene nanoparticles as a collector for removal of silica from iron ore by reverse flotation. *JOM.* 2023; 75(4): 1270-1277.

[19] Liu S, et al. Improving the properties of magnetite green pellets with a novel organic composite binder, *Materials.* 2022; 15(19): 6999.

[20] Olusola A, et al. Nutritional and structural evaluation of *Sweetenia Mycophylla* exudate gum: A potential excipient and food additive extraction purification elucidation application. 2019.

[21] Koohestani H, Nabilu M, Balooch A, Biosynthesis and investigation of antibacterial properties of green silver nanoparticles using fruit extracts of wild barberry,

- medlar (*Mespilus germanica* L.), and hawthorn, *Food Chem Adv.* 2025; 6: 100850.
- [22] Wong G, et al. Improvement on the thermal cracking performance of pellets prepared from ultrafine iron ore, *Powder Technol.* 2019; 342: 873-879.
- [23] Vermeer A, Van Riemsdijk W, Koopal L, Adsorption of humic acid to mineral particles, 1. Specific and electrostatic interactions, *Langmuir.* 1998; 14(10): 2810-2819.
- [24] Gu B, et al. Adsorption and desorption of natural organic matter on iron oxide: Mechanisms and models, *Environ Sci Technol.* 1994; 28(1): 38-46.
- [25] Zhang Y.b, et al. Adsorption of lignite humic acid onto magnetite particle surface, *J Cent South Univ.* 2012; 19(7): 1967-1972.
- [26] Yang K, Lin D, Xing B, Interactions of humic acid with nanosized inorganic oxides, *Langmuir.* 2009; 25(6): 3571-3576.
- [27] Zhao H, et al. Bonding mechanism and process characteristics of special polymers applied in pelletizing binders, *Coatings.* 2022; 12(11): 1618.
- [28] Sivrikaya O, Arol A.I, Pelletization of magnetite ore with colemanite added organic binders, *Powder Technol.* 2011; 210(1): 23-28.
- [29] Gul A, et al. Improvement of mechanical strength of iron ore pellets using raw and activated bentonites as binders, *Physicochem Probl Miner Process.* 2015; 51(1): 23-36.
- [30] Qiu G, et al. Functions and molecular structure of organic binders for iron ore pelletization, *Colloids Surf A Physicochem Eng Asp.* 2003; 224(1): 11-22.
- [31] Sivrikaya O, et al. The effect of calcined colemanite addition on the mechanical strength of magnetite pellets produced with organic binders, *Miner Process Extr Metall Rev.* 2013; 34(4): 210-222.
- [32] Tafadzwa N, et al. Investigating the effectiveness of organic binders as an alternative to bentonite in the pelletization of low grade iron ore, *Physicochem Probl Miner Process.* 2023; 59.