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## D3.2

Determination of a mathematical correlation between briquetting parameters/material properties and apparent density as well as the mechanical strength of the produced HBI (cold/hot state)

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## Abbreviations and acronyms

DRI	Direct reduced iron	
HBI	Hot briquetted iron	
ITUN	Institute of Thermal, Environmental and Resources' Process Engineering	
R&D	Research and development	
TU BAF	TU Bergakademie Freiberg	
$d$	Particle size	mm
$\Delta d$	Grain size (fraction from... to...)	mm
$Fe_{met}$	Metallic iron content	%
$p$	Briquetting pressure	MPa
$R^2$	Goodness of fit	
$R w_s (n)$	Abrasion resistance: residue on the screen with the width $w_s$ after $n$ revolutions in the abrasion drum	%
$\rho_{app}$	Apparent density	$g/cm^3$
$SSA$	Specific surface area	$m^2/g$
$TC$	Total carbon content	%
$\vartheta_p$	Briquetting temperature	$^{\circ}C$



## **Abstract**

This report gives a summary on the determination of a mathematical correlation between briquetting parameters/material properties and apparent density as well as the mechanical strength of the produced HBI (cold/hot state) on a literature-based level.

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## 1 Introduction

According to the objectives of work package WP 3, the influence of the briquetting parameters as well as the influence of the material parameters on the apparent density and mechanical strength of the HBI should be quantified in cold and hot state. A promising approach is the mathematical analysis of the results of the briquetting investigations by analysis of variances (ANOVA) and regression analysis.

In the first step, a literature research was done to identify previous research on this topic as a basis for the later analysis of the results in HBI briquetting in HBI C-Flex.

Note:

Compression and compaction are often used synonymous in literature for densification of solids (pharmacy, process engineering etc.). To guard against misunderstandings, a definition by US Pharmacopoeia for tablet progression may be used:

Compression: Reduction of bulk volume by removal of gaseous phase by external force,

Consolidation: Increase in mechanical strength by particle-particle interactions,

Compaction: Compression and consolidation by application of external force.

## 2 Literature used

The following references were identified in the literature research as highly relevant:

- [1] V. Chevrier, Ch. Ravenscroft, Direct Reduced Ironmaking Technology: Hot Briquetting Trials of DRI with Higher Carbon Levels, SEASI Quarterly Journal, 47 (2018), 4, 55 – 62
- [2] J. Gray, N. Saha-Chadhury, V. Sahajwalla, Characterisation and Corrosion of Laboratory Scale Briquettes of Reduced Iron, ISIJ International, 42 (2002) 8, 826 – 833
- [3] L. Lohmeier, R. Wollenberg, H.-W. Schröder, Investigation into Hot Briquetting of Fine-Grained Residual Materials from Iron and Steel Production, Steel research international (2020), 2000237, 1 – 10
- [4] W. M. Melfo, R. J. Dippenaar, B. J. Monaghan, Effect of particle composition on consolidation of hot briquetted iron, Ironmaking and Steelmaking, 33 (2006), 2, 93 – 100
- [5] M. Miller, Effects of Making HBI With and Without Hot Fines Recycling, AISTech - Iron and Steel Technology Conference Proceedings, Volume 2023, 450 – 458, Detroit, 05.05. – 11.05.2023 (not available yet)
- [6] A. Ruthenbeck, M. Lamb, V. Chevrier, Hot briquetting trials with variable carbon DRI, Proceedings of the Iron and Steel Technolgy Conference, Volume 2015, 649 – 658, Cleveland, Ohio, 04. – 07.05.2015
- [7] Selection of unpublished R&D Reports on Hot Briquetting of DRI-Pellets, TU Bergakademie Freiberg, ITUN (anonymised)
- [8] S. Weh: Anwendung von Verdichtungsmodellen für die Beschreibung des Agglomerationsverhaltens von Eisenträgern bei der Heißbrikettierung [Evaluation of compaction models for describing the agglomeration behaviour of iron carriers by hot briquetting], Studienarbeit [study thesis], TU Bergakademie Freiberg, Institute of Thermal, Environmental and Resources' Process Engineering, 2023

### 3 Results of the literature research

As a general result the following influencing parameters on briquette quality were identified from the literature. They can be divided in two groups:

- Raw material properties:
  - o Degree of metallisation,
  - o Total carbon content,
  - o Particle size distribution,
- Briquetting parameters:
  - o Briquetting temperature,
  - o Briquetting pressure,
  - o Briquetting time.

In the following sections of this chapter, the materials and methods are presented and the influence of selected parameters on the HBI quality are discussed. Table 1 summarises the materials, methods and results of the identified references.

#### 3.1 Material and methods

##### 3.1.1 Material

The following table characterises the used feedstocks as given in the references.

Table 1: Feedstock characterisation of the DRI samples [1,2,4,6,7]

		Chevrier et al. Ruthenbeck et al.	Gray et al.	ITUN	Melfo et al.
$F_{\text{emet}}$	%	n/a	93.6	56.9 ... 85.7	82.5 ... 84.4
$TC$	%	1.2 ... 4.3	1.5	1.0 ... 4.0	1.9 ... 0.71
$\Delta d$	mm	n/a	1.0/0.053	10/0.024 ... 30/8	0.01/0

##### 3.1.2 Methods

All authors used (hydraulic) piston presses for their experiments. The experimental setups are shown and described in the following figures.

Chevrier et al. and Ruhtenbeck et al. [1,6] use the same experimental setup and discuss (mainly) the same results. The experimental setup is shown in Figure 1.

For the briquetting tests, the figure suggests that a piston press with a forming tool consisting of an upper and a lower piston as well as a heated die was used. The DRI is preheated in vessels and placed on top of the heated die. By opening a slide gate on the bottom, the DRI falls into the die. After removing the vessel, the sample is compressed in the mould. The briquetting pressure remains constant at 200 MPa, while the applied compaction speed is not mentioned.

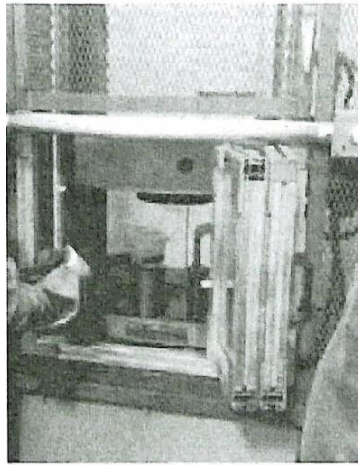


Figure 1: Experimental setup according to Chevrier et al./ Ruthenbeck et al. [1]

In the investigations of Gray et al. [2] the briquetter (Figure 2) consists of a DRI sample hopper (2), the three-part forming tool with an upper (3) and a lower (6) piston as well as the die with an inner diameter of 40 mm. This forming tool is placed in a furnace (4) to heat up the forming tool to a maximum of 700 °C.

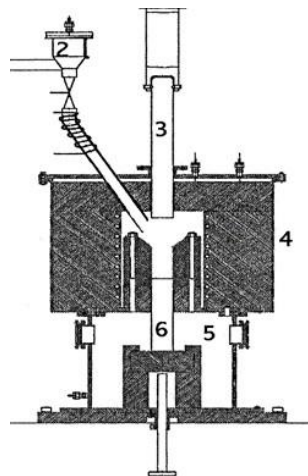


Figure 2: Experimental setup according to Gray et al. [2]

The pre-heated DRI sample is put into the sealed feeder and falls into the mould where it is compacted by lowering the upper piston. After compaction, the lower piston leaves the mould and the briquette is ejected from the die into the cooling zone (5). The briquetting pressure is set to 143 MPa. The briquetting time and compression speed are not mentioned.

At ITUN [7], a hydraulic piston press with a cooled circular forming tool (lower and upper piston as well as die, 50 mm diameter) is used for the investigations (Figure 3).



Figure 3: Experimental setup at ITUN (left-hand side: muffle furnace for pre-heating; right-hand side: hydraulic piston press)

The DRI-samples are pre-heated in a muffle furnace in small vessels to a defined briquetting temperature. The vessels are set on the cooled die. When the slide gate at the bottom of the vessel is opened, the pre-heated DRI is filled into the mould. After removing the vessel, the DRI is compressed in the mould by lowering the upper piston reaching a briquetting pressure of 150 MPa, respectively 200 MPa, with a compression speed of 10 mm/min. The briquetting time is set constant at 3 s.

Melfo et al. [4] installed the forming tool at a universal testing machine as shown in Figure 4.

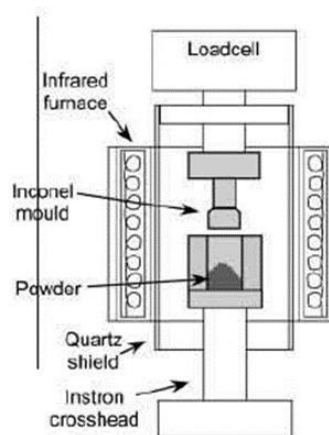


Figure 4: Experimental setup according to Melfo et al. [4]

The circular forming tool with a diameter of 10.3 mm is placed in an infrared furnace. The sample is put into the mould which is then lifted against the upper piston to compact the DRI sample with a compaction speed of 0.4 mm/s. The briquetting time is set to 5 min. The briquetting pressure is varied from  $\approx 60$  MPa to  $\approx 525$  MPa.

### 3.1.3 Parameters of evaluation

To evaluate the briquette quality, the authors use different parameters. The following table gives an overview of the used parameters of evaluation:

Table 2: Parameters to evaluate the briquette quality given in the references [1,2,4,6,7]

	<b>Chevrier et al. Ruthenbeck et al.</b>	<b>Gray et al.</b>	<b>ITUN</b>	<b>Melfo et al.</b>
Apparent density	✓	✓	✓	✓
Abrasion resistance/ durability	residue on 25 mm screen after 100 and 300 revolutions in drum 500 x 500 mm according to ISO 15967	-	Residue on 30 mm and 10 mm screen after 100 up to 1000 revolutions in drum 500 x 500 mm, 25 rpm	-
Specific surface area		✓	-	-
Compressive strength	-	-	Core compressive strength of the lying briquette with plane-parallel pistons of $d = 30$ mm	Diametrical compression test of the upright briquette between two brass pads

All authors discussed the apparent density of the produced briquettes. Only Gray et al. [4] determined the specific surface area of the briquette as an evaluation parameter of the briquette quality. Although the abrasion resistance in a cylindrical drum with similar geometry was determined by Chevrier et al./ Ruthenbeck et al. [1,6] as well as by ITUN [7], the residues on different sieves after loading were determined and the revolution speed of the drums might differ. The compressive strength was determined by Melfo et al. [4] as well as by ITUN [7]. Unfortunately, the methodology of testing was different. Melfo et al. determined the compressive strength of the upright briquette between two brass pads. At ITUN the core compressive strength of the lying briquette is determined between two plane-parallel pistons of 30 mm. It can be seen that no standardised evaluation procedure has been defined so far.

### 3.2 Influence of the briquetting temperature

The influence of the briquetting temperature on the HBI quality was discussed in the works of Gray et al., Chevrier et al./ Ruthenbeck et al. and in the R&D reports of ITUN at TU Bergakademie Freiberg [1,2,6,7].

Figure 5 shows the results of Gray et al. [2] regarding the influence of temperature variation on the apparent density and specific surface area of the briquettes.

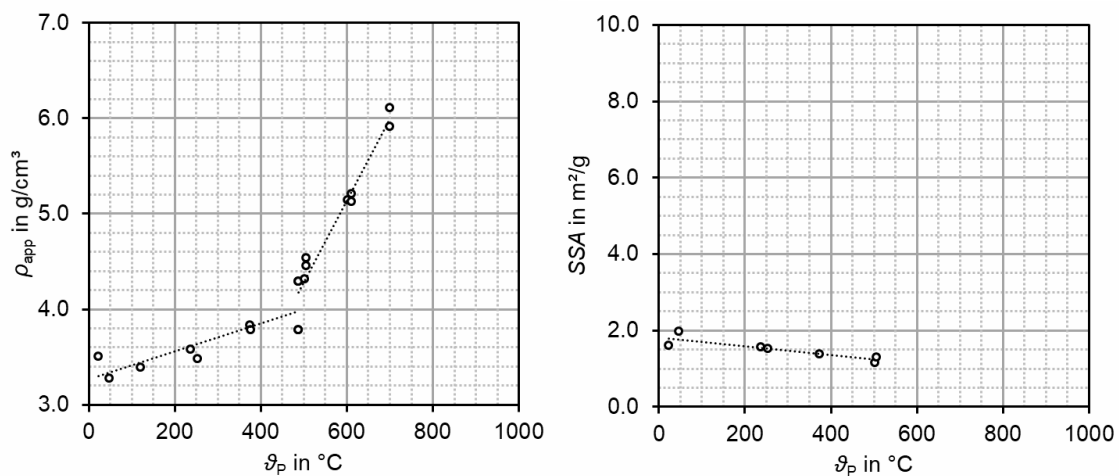


Figure 5: Apparent density (left) and specific surface area SSA (right) of HBI as a function of briquetting temperature according to Gray et al. [2]

Gray et al. varied the briquetting temperature in a wide range from room temperature to 700 °C. The briquetting pressure remained constant at 143 MPa. Generally, the increase in briquetting temperature leads to higher apparent densities and lower specific surfaces of the briquettes. For a mathematical description of the apparent density, two sections were defined: From room temperature up to 488 °C, the apparent density increases only slightly. In comparison, the increase in briquetting temperature from 500 °C to 700 °C leads to a clearly higher apparent density. In both sections, the apparent density shows a linear correlation to the briquetting temperature which can be described by the following equations:

$$\vartheta_P = 20 \dots 488 \text{ °C:} \quad \rho_{app} = 0.0014 \vartheta_P + 3.2696 \quad (1)$$

$$R^2 = 0.72$$

$$\vartheta_P = 488 \dots 700 \text{ °C:} \quad \rho_{app} = 0.0086 \vartheta_P - 0.0071 \quad (2)$$

$$R^2 = 0.95$$

The specific surface area of the briquettes was only determined for briquetting temperatures from 20 °C to 488 °C, and can be described by a linear function as well:

$$\vartheta_p = 20 \dots 488 \text{ }^\circ\text{C}: \quad SSA = -0.0012 \vartheta_p + 1.8237 \quad (3)$$

$$R^2 = 0.78$$

Chevrier et al. and Ruthenbeck et al. [1,6] discussed the same data. They varied the briquetting temperature from 600 to 800 °C at a briquetting pressure of 200 MPa. The results of their investigations are given in Figure 6. It is unclear if the abrasion resistance after 100 or 300 revolutions is shown in the following diagram.

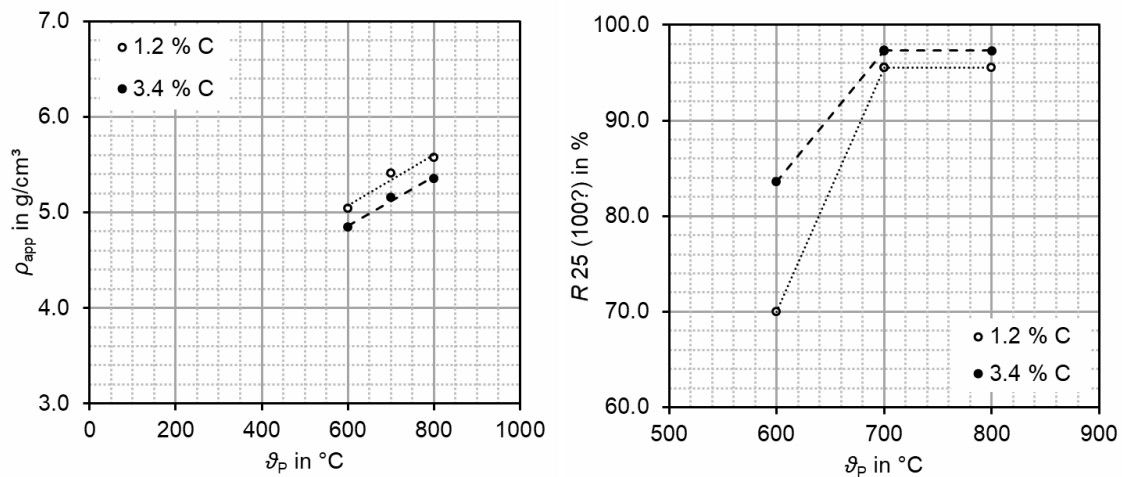


Figure 6: Apparent density (left) and abrasion resistance (right) of HBI as a function of briquetting temperature according to Chevrier et al./Ruthenbeck et al. [1,6]

Again, the apparent density shows a positive correlation with the briquetting temperature with a linear function. The abrasion resistance offers also a linear correlation with the briquetting temperature from 600 °C to 700 °C. The further increase in briquetting temperature does not lead to an increase in abrasion resistance; it remains on a constant level. Furthermore, an increase in the carbon content of the DRI leads to a decrease in apparent density and abrasion resistance. While apparent density at higher carbon content is almost parallel translated, the higher carbon content leads to a considerably lower abrasion resistance at 600 °C than for higher temperatures.

The following equations describe the mathematical correlation of the apparent density and briquetting temperature for the given literature data:

$$C = 1.2 \text{ } \%: \quad \rho_{\text{app}} = 0.0027 \vartheta_p + 3.4831 \quad (4)$$

$$R^2 = 0.95$$

$$C = 3.4 \text{ } \%: \quad \rho_{\text{app}} = 0.0026 \vartheta_p + 3.3294 \quad (5)$$

$$R^2 = 0.98$$

The correlation of abrasion resistance and briquetting temperature are given in the following equations:

$$C = 1.2 \%, \quad R_{25}(100?) = 0.1376 \vartheta_p + 0.9631 \quad (6)$$

$$\vartheta_p = 600 \dots 700 \text{ }^\circ\text{C}: \quad R^2 = 1.00$$

$$C = 3.4 \%, \quad R_{25}(100?) = 0.2552 \vartheta_p - 83.146 \quad (7)$$

$$\vartheta_p = 600 \dots 700 \text{ }^\circ\text{C}: \quad R^2 = 1.00$$

The investigations at ITUN [7] were done at a higher briquetting pressure of 200 MPa. The briquetting temperature was varied from room temperature to 1000 °C. In these investigations, four different DRI samples with different carbon content were used. Figure 7 shows the results of the investigations.

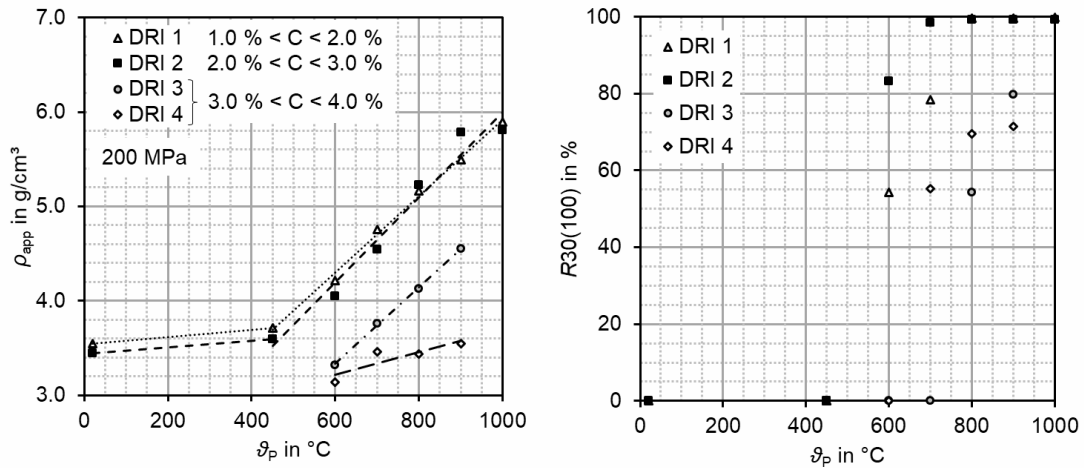


Figure 7: Apparent density (left) and abrasion resistance (right) of HBI as a function of briquetting temperature according to R&D results at ITUN [7]

Similar to the previous results, a higher briquetting temperature leads to higher apparent densities of the formed HBI. Along the lines of Gray et al. [2] a mathematical description is possible by dividing the data points in two sections from room temperature to 450 °C and from 450 °C to 1000 °C. In comparison to Gray et al., the apparent densities are on a lower level even at a comparable carbon content due to a lower  $\text{Fe}_{\text{met}}$  fraction. A higher carbon content leads to a lower apparent density.

$$\text{DRI 1:} \quad \rho_{app} = 0.0004 \vartheta_p + 3.5382 \quad (8)$$

$$\vartheta_p = 20 \dots 450 \text{ }^\circ\text{C}: \quad R^2 = 1.00$$

$$\text{DRI 1} \quad \rho_{app} = 0.0040 \vartheta_p + 1.8772 \quad (9)$$

$$\vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}: \quad R^2 = 1.00$$

$$\text{DRI 2:} \quad \rho_{app} = 0.0004 \vartheta_p + 3.4390 \quad (10)$$

$$\begin{aligned} \vartheta_p = 20 \dots 450 \text{ }^\circ\text{C}: & \quad R^2 = 1.00 \\ \text{DRI 2} & \quad \rho_{app} = 0.0045 \vartheta_p + 1.4949 \end{aligned} \quad (11)$$

$$\begin{aligned} \vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}: & \quad R^2 = 0.97 \\ \text{DRI 3:} & \quad \rho_{app} = 0.0041 \vartheta_p + 0.8950 \end{aligned} \quad (12)$$

$$\begin{aligned} \vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}: & \quad R^2 = 1.00 \\ \text{DRI 4:} & \quad \rho_{app} = 0.0012 \vartheta_p + 2.4900 \end{aligned} \quad (13)$$

$$\vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}: \quad R^2 = 0.77$$

The abrasion resistance of the HBI correlates with the briquetting temperature as well. Along the lines of Chevrier et al./ Ruthenbeck et al. a [1,6] minimum briquetting temperature is needed to produce briquettes with a suitable abrasion resistance. For the DRI sample with a carbon content under 3.0 %, a minimum temperature of 600 °C is needed to create HBI which does not break (completely) during tumbling. If the carbon content exceeds 3.0 % a minimum temperature of 700 °C, respectively, 800 °C is necessary to prevent total breakage of the HBI during loading. After a section with linear correlation of abrasion resistance and briquetting temperature, a plateau with constant abrasion resistance is reached.

The following equations describe the correlation of abrasion resistance and briquetting temperature based on the data points from the specific references:

$$\text{DRI 1:} \quad R_{30(100)} = 0.2848 \vartheta_p - 123.5 \quad (14)$$

$$\vartheta_p = 400 \dots 800 \text{ }^\circ\text{C}: \quad R^2 = 0.98$$

$$\text{DRI 2} \quad R_{30(100)} = 0.4067 \vartheta_p - 176.66 \quad (15)$$

$$\vartheta_p = 400 \dots 700 \text{ }^\circ\text{C}: \quad R^2 = 0.93$$

$$\text{DRI 3:} \quad R_{30(100)} = 0.399 \vartheta_p - 274.5 \quad (16)$$

$$\vartheta_p = 700 \dots 900 \text{ }^\circ\text{C}: \quad R^2 = 0.96$$

$$\text{DRI 4} \quad R_{30(100)} = 0.3475 \vartheta_p - 201.68 \quad (17)$$

$$\vartheta_p = 600 \dots 800 \text{ }^\circ\text{C}: \quad R^2 = 0.97$$

### 3.3 Influence of the briquetting pressure

The influence of briquetting pressure was investigated by Melfo et al. [4] as well as by ITUN's researchers [7].

The results of HBI briquetting at different briquetting pressure done by Melfo et al. are shown in Figure 8. Albeit there is a large set of data and regression curves are plotted in the diagrams, no equations are given. Additionally, the quality and size of the figures did not allow to determine the correct data points from the figures as it was done for the other references.

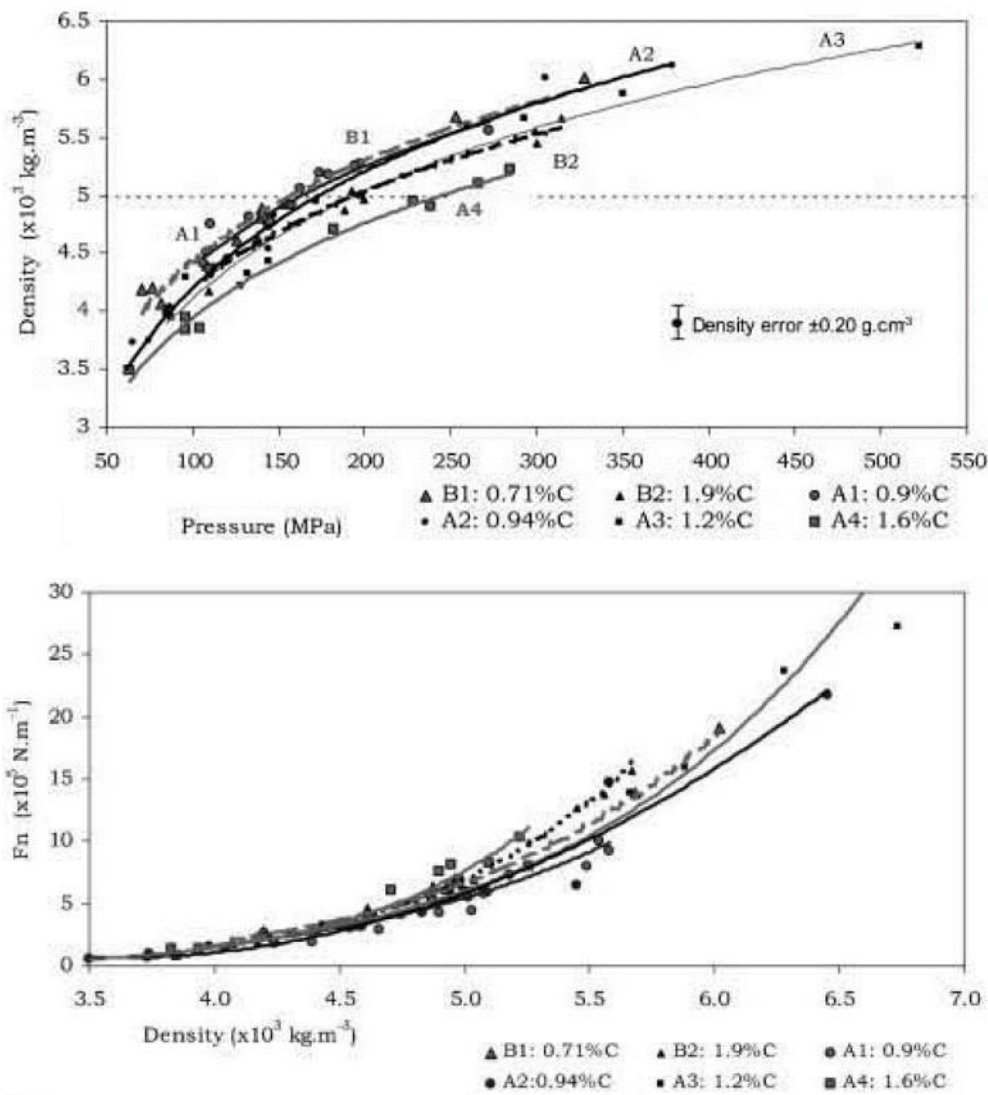


Figure 8: Influence of briquetting pressure on apparent density (above) and fracture force as a function of apparent density of the HBI (below) according to Melfo et al. [4]

Nevertheless, the increase in briquetting pressure leads qualitatively to higher briquette quality. The data hypothesises restricted growth of the density up to a physical maximum. If the carbon content of the DRI increases, the apparent density of the briquettes decreases at a constant briquetting pressure. This means, to create HBI of the same apparent density out of DRI with higher carbon content, the briquetting pressure has to be increased. To evaluate the compressive strength, the fracture force of the briquettes is shown as a function of the apparent density. It shows a positive correlation between fracture force and apparent density, which might be described by an exponential correlation.

The results of the investigations at ITUN [7] are shown in Figure 9.

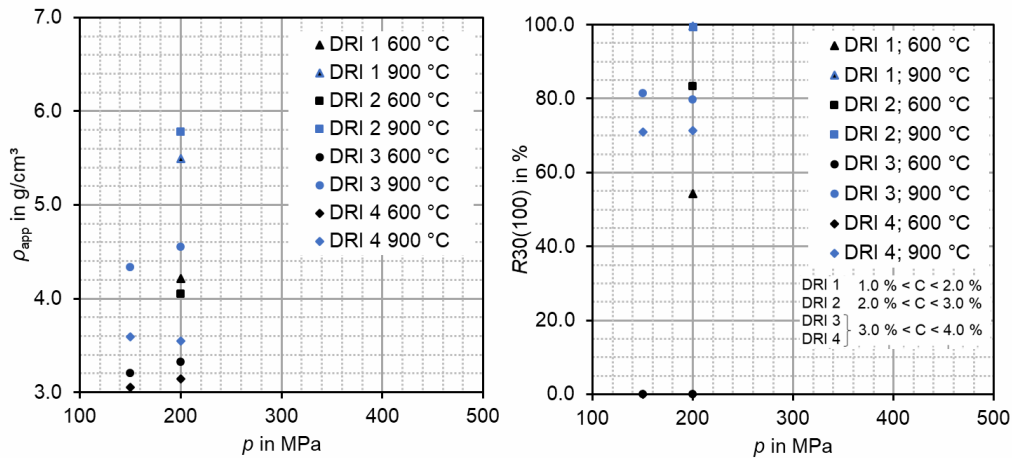


Figure 9: Apparent density (left) and abrasion resistance (right) as a function of briquetting pressure according to the investigations at ITUN [7]

As shown in the diagrams, a pressure variation was only done for two DRI samples with higher carbon content for a pressure of 150 MPa and 200 MPa. As only two data points are available, a linear correlation could be determined but the value of information would be limited. However, tendencies are clearly visible: An increase in briquetting pressure leads to an increase in apparent density of the formed HBI. The abrasion resistance of the HBI is not affected by the change in briquetting pressure and remains on a constant level.

### 3.4 Influence of the carbon content

Chevrier et al. [1] systematically investigated the influence of the carbon content of the DRI on the HBI quality. The results of this investigation are given in Figure 10. As mentioned in the beforehand discussed results, an increase in carbon content (TC) leads to a reduction of HBI quality. Chevrier et al. varied the carbon content from  $\approx 1\%$  to  $\approx 4\%$ . The results suggest a negative linear correlation between apparent density and carbon content. The abrasion resistance of the HBI shows a negative correlation with the carbon content as well, although the effect is on a lower level. The correlations can be described with the following equations:

$$\text{Ore 1:} \quad \rho_{app} = -0.1892 TC + 5.5897 \quad (18)$$

$$R^2 = 0.97$$

$$\text{Ore 2} \quad \rho_{app} = -0.1675 TC + 5.7157 \quad (19)$$

$$R^2 = 0.99$$

$$\text{Ore 1:} \quad R30(100) = 0.8782 TC + 99,032 \quad (20)$$

$$R^2 = 0.98$$

Ore 2:  $R_{30(100)} = 0.6561 TC + 98.641$  (21)  
 $R^2 = 0.87$

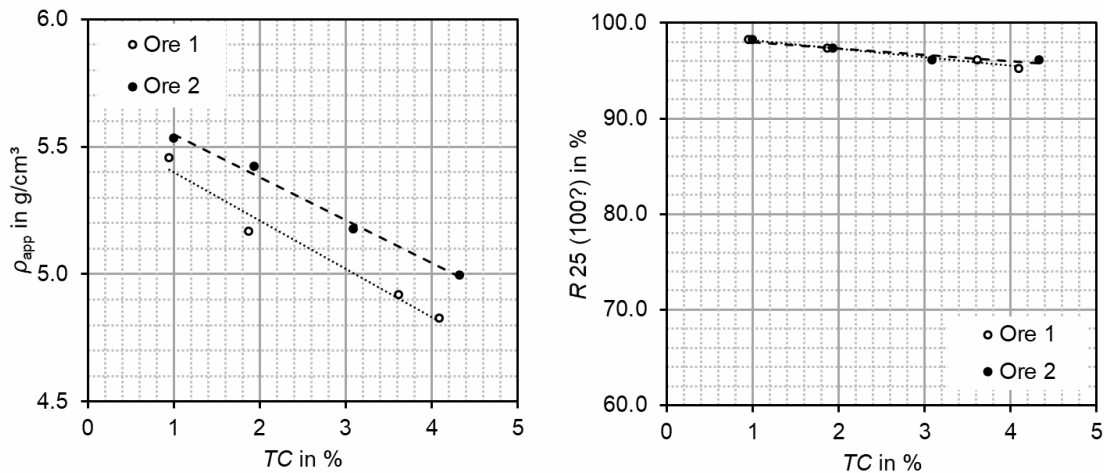


Figure 10: Apparent density (left) and abrasion resistance (right) of the HBI as a function of the carbon content of DRI pellets according to Chevrier et al. [1]

### 3.5 Modelling of the compaction behaviour

Additionally, to the mathematical description of correlations between influencing variables and quality parameters of HBI briquetting, the compaction behaviour of raw materials can be described by empiric models calculated by regression analysis. In her assignment paper S. Weh (ITUN) evaluated various empiric models for the description of press agglomeration of DRI and other metallurgical by-products or residual materials.

The following models were evaluated:

Table 3: Evaluated compaction models in the assignment paper of Weh at ITUN [8]

Linear compaction models	Non-linear compaction models
Heckel	Cooper-Eaton
Kawakitta-Lüdde	Shapiro
Walker	Comoglu
	Adapa, Tabil, Schoenau

In conclusion, the models of Kawakitta-Lüdde (linear) and Shapiro (non-linear) offered the best results to describe the compaction behaviour of DRI.

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## Conclusion

The results of the literature research can be summarised as follows:

- In general, the trends of all parameters are matching each other for all discussed references. Although the quantitative correlation behaviour varies due to different sample materials and experimental procedures.
- The apparent density of HBI shows a positive linear correlation of the briquetting temperature. For a good mathematical correlation, the data should be analysed in two temperature sections: The first should run from room temperature to  $\approx 500$  °C, the second section from  $\approx 500$  °C to (max.) 1000 °C.
- The abrasion resistance of the HBI is also dominated by the briquetting temperature. However, a minimum temperature is required to acquire a sufficient mechanical strength. This minimum temperature depends on the carbon content of the DRI; a lower carbon content generally requires a lower minimum briquetting temperature to achieve briquettes with high strength.
- Both, the apparent density as well as the mechanical strength of the briquettes are also positively correlated to the briquetting pressure. The apparent density seems to follow a saturation curve with increasing briquetting pressure. Unfortunately, the calculation of a mathematical correlation from the available data was not possible yet.
- As mentioned above, an increasing carbon content leads to lower apparent density and mechanical strength of the briquettes. Apparent density and abrasion resistance follow a negative linear correlation.

In further investigations, the results of the research papers should be combined by determination of a compaction ratio or density ratio to enable the direct comparison of the different results. On the basis of this report, it will be possible to evaluate the experimental results on HBI briquetting of the ongoing project and describe the compaction behaviour by suitable models.

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# Appendix

Table 1: Overview of data identified in the literature research

		Chevrier et al. Ruthenbeck et al.	Gray et al.	ITUN	Melfo et al.	
Raw material characteristics	$Fe_{met}$	%	n/a	93.6	56.9 ... 85.7	82.5 ... 84.4
	TC	%	1.2 ... 4.3	1.5	1.0 ... 4.0	0.71 ... 1.9
	$\Delta d$	mm	n/a	1.0/0.53	10/0.24 ... 30/8	0.01/0
Compaction parameters	type of press	Hydraulic piston press	Hydraulic piston press	Hydraulic piston press	Hydraulic piston press	
	$d_{Briquette}$	mm	n/a	40	50	10.3
	$p$	MPa	200	143	150, 200	60 ... 525
Parameters of evaluation	Apparent density	+	+	+	+	
	Abrasion resistance/ Durability	Residue on 25 mm screen after 100 and 300 revolutions in drum 500 x 500 mm according to ISO 15967	+	+	Residue on 30 mm and 10 mm screen after 100 up to 1000 revolutions in drum 500 x 500 mm, 25 rpm	-
	Specific surface area	-	+	-	-	-
	Compressive strength	-	-	-	Core compressive strength of the lying briquette with plane-parallel pistons of $d = 30$ mm	Diametrical compression test of the upright briquette between two brass pads
Influence of briquetting temperature	Apparent density	Area of validity	TC = 1.2 %	$\vartheta_p = 20 \dots 488 \text{ }^\circ\text{C}$	DRI 1 $\vartheta_p = 20 \dots 450 \text{ }^\circ\text{C}$	
		equation	$\rho_{app} = 0.0027 \vartheta_p + 3.4831$	$\rho_{app} = 0.0014 \vartheta_p + 3.2696$	$\rho_{app} = 0.0004 \vartheta_p + 3.5382$	
		Goodness of fit	$R^2 = 0.95$	$R^2 = 0.72$	$R^2 = 1.00$	
		Area of validity	TC = 3.4 %	$\vartheta_p = 488 \dots 700 \text{ }^\circ\text{C}$	DRI 1 $\vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}$	
		equation	$\rho_{app} = 0.0026 \vartheta_p + 3.3294$	$\rho_{app} = 0.0086 \vartheta_p - 0.0071$	$\rho_{app} = 0.0004 \vartheta_p + 1.8772$	
		Goodness of fit	$R^2 = 0.98$	$R^2 = 0.95$	$R^2 = 1.00$	
		Area of validity			DRI 2 $\vartheta_p = 20 \dots 450 \text{ }^\circ\text{C}$	
		equation			$\rho_{app} = 0.0004 \vartheta_p + 3.4390$	
		Goodness of fit			$R^2 = 1.00$	
		Area of validity			DRI 2 $\vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}$	
		equation			$\rho_{app} = 0.0045 \vartheta_p + 1.4949$	
		Goodness of fit			$R^2 = 0.97$	
		Area of validity			DRI 3 $\vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}$	
		equation			$\rho_{app} = 0.0041 \vartheta_p + 0.8950$	
		Goodness of fit			$R^2 = 1.00$	
	Area of validity			DRI 4 $\vartheta_p = 450 \dots 1000 \text{ }^\circ\text{C}$		
	equation			$\rho_{app} = 0.0012 \vartheta_p + 2.4900$		
	Goodness of fit			$R^2 = 0.77$		
	Abrasion resistance/ Durability	Area of validity	TC = 1.2 %, $\vartheta_p = 600 \dots 700 \text{ }^\circ\text{C}$		DRI 1 $\vartheta_p = 400 \dots 800 \text{ }^\circ\text{C}$	
		equation	$R_{25}(100?) = 0.1376 \vartheta_p + 0.9631$		$R_{30}(100) = 0.2848 \vartheta_p - 123.5$	
		Goodness of fit	$R^2 = 1.00$		$R^2 = 0.98$	
		Area of validity	TC = 3.4 %, $\vartheta_p = 600 \dots 700 \text{ }^\circ\text{C}$		DRI 2 $\vartheta_p = 400 \dots 700 \text{ }^\circ\text{C}$	
		equation	$R_{25}(100?) = 0.2552 \vartheta_p - 83.146$		$\rho_{app} = 0.4067 \vartheta_p - 176.66$	
		Goodness of fit	$R^2 = 1.00$		$R^2 = 0.93$	
		Area of validity			DRI 3 $\vartheta_p = 700 - 900 \text{ }^\circ\text{C}$	
		equation			$\rho_{app} = 0.399 \vartheta_p + 274.5$	
		Goodness of fit			$R^2 = 0.96$	
		Area of validity			DRI 4 $\vartheta_p = 600 \dots 800 \text{ }^\circ\text{C}$	
		equation			$\rho_{app} = 0.3475 \vartheta_p - 201.68$	
		Goodness of fit			$R^2 = 0.97$	
Specific surface area		Area of validity		$\vartheta_p = 20 \dots 488 \text{ }^\circ\text{C}$		
		equation		$SSA = - 0.0012 \vartheta_p + 1.8237$		
		Goodness of fit		$R^2 = 0.78$		



Continuation of Table 1:

		Chevrier et al. Ruthenbeck et al.	Gray et al.	ITUN	Melfo et al.
Influence of briquetting pressure	Apparent density	Area of validity		DRI 3 $\vartheta_p = 600; 900 \text{ }^\circ\text{C}$ $p = 150; 200 \text{ }^\circ\text{C}$	not evaluable from reference
		range of quality parameter		$\vartheta_p = 600 \text{ }^\circ\text{C}$ : $\rho_{app} = 3.200; 3.320 \text{ g/cm}^3$ $\vartheta_p = 900 \text{ }^\circ\text{C}$ : $\rho_{app} = 4.334; 4.550 \text{ g/cm}^3$	
		Area of validity		DRI 4 $\vartheta_p = 600; 900 \text{ }^\circ\text{C}$ $p = 150; 200 \text{ }^\circ\text{C}$	
		range of quality parameter		$\vartheta_p = 600 \text{ }^\circ\text{C}$ : $\rho_{app} = 3.050; 3.140 \text{ g/cm}^3$ $\vartheta_p = 900 \text{ }^\circ\text{C}$ : $\rho_{app} = 3.590; 3.550 \text{ g/cm}^3$	
	Abrasion resistance/ Durability	Area of validity		DRI 3 $\vartheta_p = 600; 900 \text{ }^\circ\text{C}$ $p = 150; 200 \text{ }^\circ\text{C}$	
		range of quality parameter		$\vartheta_p = 600 \text{ }^\circ\text{C}$ : $R_{30}(100) = 0; 0 \%$ $\vartheta_p = 900 \text{ }^\circ\text{C}$ : $R_{30}(100) = 81.4; 79.8 \%$	
		Area of validity		DRI 4 $\vartheta_p = 600; 900 \text{ }^\circ\text{C}$ $p = 150; 200 \text{ }^\circ\text{C}$	
		range of quality parameter		$\vartheta_p = 600 \text{ }^\circ\text{C}$ : $R_{30}(100) = 0; 0 \%$ $\vartheta_p = 900 \text{ }^\circ\text{C}$ : $R_{30}(100) = 71.0; 71.4 \%$	
Influence of carbon content	Apparent density	Area of validity	$TC = 1.2 \%$		
		equation	$\rho_{app} = - 0.1892 TC + 5.5897$		
		Goodness of fit	$R^2 = 0.97$		
		Area of validity	$TC = 3.4 \%$		
	equation	$\rho_{app} = - 0.1675 TC + 5.7157$			
	Goodness of fit	$R^2 = 0.99$			
	Abrasion resistance/ Durability	Area of validity	$TC = 1.2 \%$		
		equation	$R_{30}(100) = - 0.8782 TC + 99.032$		
		Goodness of fit	$R^2 = 0.98$		
		Area of validity	$TC = 3.4 \%$		
equation		$\rho_{app} = 0.6561 TC + 98.641$			
Goodness of fit		$R^2 = 0.87$			