LOW ENERGY SPENT COFFEE GROUNDS BRIQUETTING WITH ORGANIC BINDERS FOR BIOMASS FUEL MANUFACTURING

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ABSTRACT

This paper analyzes the ability of the spent coffee grounds (SCG) for briquettes production with xanthan and guar gums as binders. Briquettes were manufactured at room temperature, at 15%, 20%, 25% and 30% of moisture, at 8 MPa, 10 MPa and 12 MPa of compaction pressure and at 5 and 10% of binder dosage. Combination of 10% of xanthan, 15% of moisture, at 12 MPa, reached the highest dry density, 0.819 g/cm^3. The combination of 5% of xanthan, 30% of moisture, compacted at 12 MPa was the most durable with a loss of mass of 3.9%. No relationships were established among water absorption and binder type, binder dosage, manufacturing moisture or compaction pressure. The lowest water absorption value, 0.25%, corresponded to the combination with 5% of xanthan, 30% of moisture, compacted at 10 MPa. The lowest heating value achieved by SCG was 25,399 J/g. Guar 5% and 10% combinations achieved 24,398 J/g and 24,321 J/g respectively. Xanthan gum 5% and 10% dosages attained 24,450 and 23,503 J/g. Binder decreased volatiles, increased fixed carbon content and decreased nitrogen content. Guar gum decreased SCG nitrogen content by 15.92% for the 5% and by 16.92% for the 10% dosage combinations, respectively. Xanthan nitrogen reduction attained 13.43% for the 5% and 14.43% for the 10% of dosage. The raw SCG ash production was 0.66%. This value increased to 0.81 % and 0.97% with 5% and 10% of xanthan gum, meanwhile guar decreased it to 0.57% and 0.52%, at 5% and 10% of dosage.

KEYWORDS

Spent coffee grounds; biomass fuel; briquette; xanthan gum; guar gum.

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1. INTRODUCTION

Biomass is receiving an increasing interest as an effective and renewable source of energy alternative to fossil fuels. Its use has demonstrated its ability to decrease the greenhouse and acid gases emissions, the reduction of the energy production costs and saving valuable and non-renewable resources such as petroleum or coal [1–4]. Despite its potential, biomass shows two major disadvantages as sustainable source of green energy: Nowadays most of biomass solid fuels are mainly produced from wood forest wastes whose availability is limited. The worldwide increase of the energy needs could result in the setting up of more and more energy crops which could compete with food crops for arable lands. This could be supposed to be a big issue, mainly in developing countries where biomass provides 20-33% of the total energy consumption. Agro-industry wastes have demonstrated their ability for biomass fuel production [5–10]. Unprocessed biomass bulk density and its usually small and irregular particle shape and size presents difficulty in its storage, transportation, handling and feeding. This concern is usually overcome by densification by high pressure and high temperature compaction processes. This way a suitable commodity is produced with homogenous size and shape, improved density, higher caloric density and lower emissions of particles and green-house gases, among other improved properties [3,4,7,11,12]. However not all the agro-industry wastes have the ability to become suitable solid fuel. One of the most usual limitations is the lack of binding substances that produces densified biomass with insufficient mechanical strength. In these cases it is required the use of organic or mineral binders to improve the final product quality [8,13].

Spent Coffee Grounds (SCG) is a worldwide distributed agro-industry waste. The large amounts of SCG generated every day, its pollutant potential, the lack of any effective valorization way and its good lower heating power, make the SCG a high potential green energy source Coffee is the most popular beverage in the word and the second traded commodity [14], annual consumption of coffee bean is considered to be of 9.44 millions of tonnes [15]. SCG has a high pollutant potential due to the toxic nature of substances contained like caffeine, tannins, or polyphenols and requires high quantities of oxygen to be degraded [9,16–18]. Seco et al. [19] demonstrated the low ability of this waste for its densification and the potential of xanthan gum as binder for the SCG briquettes manufacturing under low pressure and low temperature manufacturing conditions. This paper continues the works carried out in the Public University of Navarre for the valorization of the SCG as solid biomass fuel [19]. The aim of the investigation carried out was to increase the nowadays available knowledge about the production of SCG briquettes with organic binders. The effect of the use of xanthan and guar gums at two dosages was investigated. Thus, the optimization of the manufacturing parameters could allow a more effective valorization of large amounts of this waste, increasing the sustainability of biomass solid fuels in accordance with the circular economy principles.

2. MATERIALS AND METHODS

One tonne of SCG was used for the laboratory investigation. The sample was homogenized and physically- chemically characterized before testing. Details about this sample and the xanthan gum used can be found in [19]. In this research, in addition to xanthan, guar gum was used as binder. It is a water soluble polysaccharide polymer, widely used as food thickener which is obtained from the *Cyamopsis tetragonoloba* seeds.

Every briquette was manufactured by filling a 65 mm diameter and 12 cm height cylindrical mold, with 100g of material from every combination, being afterwards compressed at 8 MPa, 10 MPa and 12 MPa. Once the compaction pressure was reached, the samples were immediately unmolded. Manufacturing moisture contents were fixed at 15%, 20%, 25% and 30%. More details about the manufacturing methodology are explained in [19]. Briquettes manufacturing parameters are shown in Table 1.

TABLE 1

Following the procedure of the previous paper, each combination was designated by the code GT-MC-BI-DO-PR being:

GT the SCG type: raw (*R*)

MC the moisture content, followed by *W*

DO the dosage of the binder

BI the binder type: xanthan (*X*) or guar (*G*)

PR the compaction pressure

For example the code R15W5X8 identifies the combination containing raw SCG with 15% of wet content, dosage of 5% of xanthan gum and compaction pressure of 8 MPa. Samples were maintained at room conditions (20º C and 50% RH) for a week before testing. Dry density, durability and water absorption were stated for the characterization of the quality of the briquettes. Dry density was considered representative of the ability of biomass to be densified, durability test shows the resistance of the briquettes to transport and handling and water absorption is an estimator of durability against environmental conditions. Durability was characterized by means of an abrasion and knocking test adapted from the European Standard UNE EN ISO 17831-2. Details about the durability test carried out are shown in [19]. From a chemical point of view, proximate and ultimate analysis as well as combustion tests were considered. Proximate analyses were carried out in a METTLER-TOLEDO TG-DSC2 system. Tests were conducted with 10 mg of sample under an air flux of 100 ml/min and a heating rate of 10 C/min. A N_2 atmosphere was used from room temperature to 600º C and a N_2:O_2 (4:1) atmosphere from 600º C to 900º C. Combustion tests were carried out in the same equipment and the same conditions except the atmosphere, being a N_2:O_2 (4:1) oxidizing mix from room temperature to 900º C. Elemental compositions of the raw materials were analyzed by means of a ThermoFinnigan FlashEA 1112 analyzer. Tests were conducted in Helium atmosphere at 900º C with oxygen injection and chromatographic columns gases separation. Lower Heating Value (LHV) was determined using an IKA C5003 calorimeter.

3. RESULTS AND DISCUSSION

3.1. DRY DENSITY

Figure 1 shows the dry densities reached by all the combinations. The results obtained by the raw SCG with no binder were added as reference.

FIGURE 1

For both binders and every moisture combination briquette dry density increased as compaction pressure did. It was also observed an indirect relationship between the moisture content and sample dry densities. This is due to the fact that water partially fills the pores of the mixes, avoiding the occupation of these pores by the SCG particles during compaction. Combinations of 10% of xanthan compared to those of 5%, showed an increase of dry density for 15%, 20% and 25% of water content. For 30% of water content a decrease of the sample densities was observed for 10% of xanthan gum dosage. The combination R15W10X12 reached the highest dry density, 0.819 g/cm^3, whereas the lowest value, 0.672 g/cm^3, was achieved by the combination R30W10X8. Guar gum combinations reached lower density values than those containing xanthan gum for the same binder dosage, moisture content and compaction pressure, showing lower compaction ability. This binder achieved its highest dry density value for the combination R15W5G12 with 0.768 g/cm^3 and its lowest value for the combination R30W10G8 with 0.652 g/cm^3, respectively.

3.2. DURABILITY

Figures 2-5 show the results obtained from briquettes containing both binders after the durability test. Raw SCG samples were not tested because of the weakness of this combination without binder whose samples broke up when handling.

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

Keeping constant the manufacturing parameters, durability test results improved as moisture content increased for every dosages and compaction pressures. This demonstrates the beneficial effect of using binders, the moisture content of the samples and the compaction pressure, on the briquettes durability. Water acts as particle lubricant, generates van der Waals' forces by increasing the area of contact between particles and solubilizes the gums developing their binding ability [2,7]. 15% and 20% of moisture content were insufficient to produce durable briquettes, getting the combination R20W5X8 the best result, having lost 65.7% of the initial mass, at the end of the test. Among the combinations with 5% of xanthan gum, the best durability results were reached for the 30% of moisture content. Durability did not show any direct relationship with the compaction pressure. The best result was achieved at 12 MPa of compaction pressure, with a lost mass of 3.9% after 300 seconds test. At 8 MPa and 10 MPa, 4.0% and 4.7% of lost mass were reached respectively. When the dosage of xanthan gum increased up to 10% keeping constant the other manufacturing parameters, the mass losses increased compared to 5%. For 10% of dosage the lowest loss of mass was achieved by the combination R30W10X10, with 9.1%, followed by R30W10X12, with 21.9% and R30W10X12 with 22.5% of loss of mass respectively.

In the case of the guar gum combinations, a similar behavior to xanthan samples was observed: durability increased as moisture content did, no relationship between energy compaction and durability was observed and 5% of dosage reached better durability values than 10%. The best durability result of the guar combinations was obtained by the R30W5G12 samples, with a loss of mass of 19.8%. It is worth to notice that by comparing combinations with the same parameters but with different binder, guar gum combinations achieved worse results than xanthan gum ones did.

3.3. WATER ABSORPTION

Figures 6-9 show the results obtained by the briquette samples in the water absorption test.

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

All the combinations showed an increase of absorbed water throughout testing time. No relationships were observed among water absorption and binder type, binder dosage, manufacturing moisture or compaction pressure. Among 5% of xanthan gum samples the highest water absorption value was reached by the combination R15W5X8 samples with 1.08%. The lowest water absorption was attained by the combination R30W5X10, with 0.25%. For 10% of xanthan gum, water absorption oscillated between 1.10% and 0.32% for the combinations R30W10X8 and R30W10X10, respectively. Among the samples with 5% of guar gum the higher water absorption was achieved by the combination R15W5G10, with 1.17% and the lowest by R15W5G12 with 0.59%. Finally, for 10% of guar gum combinations, water absorption oscillated between 1.26% and 0.75% for R20W10G12 and R30W10G8, respectively. Considering that water absorption values are not higher than 1%, neither a significant trend can be observed in the different combinations, nor significant differences between binders can be stated.

3.4. COMBUSTION CHARACTERIZATION

Table 2 shows the proximate and ultimate analyses of the different combinations as well as their LHV.

TABLE 2

SCG showed adequate combustion characteristics compared to other biomass types, specially its low ashes content [2,7,20–23]. It was found that the use of both binders decreased the samples volatile content and increased the fixed carbon. Thus, combinations with 5% and 10% of xanthan gum showed a decrease of volatiles content to 76.35% and 75.85% meanwhile the combinations with 5% and 10% of guar gum reached 76.43% and 76.33%, respectively. Considering the fixed carbon, combinations with 5% and 10% of xanthan gum increased the SCG value from 18.00% to 19.01% and 19.05% respectively. Combinations with 5% and 10% of guar gum reached 19.07% and 19.20%, respectively. The decrease of volatiles and the increase of fixed carbon could suggest a more stable combustion properties of the combinations containing binder combinations compared to the raw SCG, slightly better for the guar than for the xanthan gum. The ash content of the SCG, 0.66%, increased to 0.81 % and 0.97% with 5% and 10% for the xanthan gum samples respectively, pointing up a slight decrease of the quality as solid fuel, but maintaining the ash content lower than 6% required by Standard ISO 17225-7 Standard for non-woody briquettes. Guar gum decreased the ash content to 0.57% and 0.52% with 5% and 10% of dosage, respectively. This suggest another improved quality as fuel of the guar combinations as is their lower combustion wastes generation. Ultimate analysis pointed up a decrease of the nitrogen content in the samples treated with both binders which could suppose a potential decrease of the nitrogen based compound emissions during combustion. This is more evident when guar gum is used as binder, whose combinations with 5% and 10% of guar gum lowered the nitrogen content by 15.95% and by 16.92% respectively, compared to the raw SCG.

Xanthan combinations N reduction achieved 13.43% with the 5% and 14.43% with 10% of gum dosage respectively. None of the combinations tested showed S content, so S compound emissions are not expected in the combustion of any combinations. Finally, lower heating value of the raw SCG, 25,399 J/g, decreased with both binders, especially for xanthan gum combinations. This is due to the partial substitution of higher energy SCG compounds by these lower energetic value gums. As expected, LHV showed an indirect relationship with binder dosage. Thus, guar 5% and 10% combinations achieved 24,398 J/g and 24,321 J/g, respectively. Xanthan gum 5% attained 24,450 J/g, reaching the lowest value the combination containing 10% of xanthan gum, of 23,503 J/g.

Figure 10 shows the TG, DTA and DTG profiles of the mixes tested.

FIGURE 10

TG curves from all the combinations showed dewatering, volatiles combustion, fixed carbon combustion and burnout stages. These curves suggest a lower content of volatiles and fixed carbon of binder combinations compared to raw SCG in apparent contradiction with the values showed in Table 2. This was attributed to the close results obtained from each combinations, the instrumental errors and inhomogeneities of the small samples size (about 10 mg). Xanthan gum DTA curves showed a decrease of the intensity of the heatflow peaks corresponding to the fixed carbon compared to the SCG sample. It was also observed a decrease of their temperatures from 515º C to the range of 500-505º C. Compared to SCG, the intensity of the xanthan combinations volatile peaks increased, appearing these peaks at lower temperatures, decreasing from 330º C to the range of 310º-318º C. In the guar gum combinations the intensity of the fixed carbon peaks also decreased and their temperatures changed to roughly 470º C. Guar combinations volatile peaks intensity increased, and their temperature changed to roughly 310º C. For both gums, peak intensity variations were directly related to their dosages. DTG curves showed an increasing combustion rate for gum combinations in the range of the 260-380º C, corresponding to the combustion of volatile compounds. These results suggest a lower quality on combustion of the combinations containing gums and do not match with the volatile contents shown in Table 2, by the same reasons than DTA curves. The highest mass loss rate increase was reached by the 10% guar gum sample, followed by the 5% xanthan, 5% guar and 10% xanthan. It was also noticeable the decrease of the temperature of the secondary peaks compared to the raw SCG combination. It was also observed a decrease of the rate peak temperatures, compared to SCG.

4. CONCLUSIONS

Xanthan and guar gums have demonstrated their ability for SCG briquettes manufacturing by a low pressure and low temperature process. Meanwhile raw SCG briquettes were not functional because of their lack of consistence, some of the samples containing gums showed improved properties against handling, feeding and environmental conditions. The gum type, dosage and moisture content demonstrated to be the most important manufacturing parameters to manufacture briquettes with the required physical quality. Thus, the best results were obtained with a 5% of xanthan gum and 30% of moisture content. When combustion characteristics were analyzed, results were not conclusive: the use of gums decreased the LHV of the SCG and nitrogen compound emissions. Xanthan increased ashes generation meanwhile guar decreased it. Volatile or fixed carbon content as well as combustion quality estimators got contradictory results which avoided state clear combustion quality differences between the raw SCG and mixes where gum additives were added.

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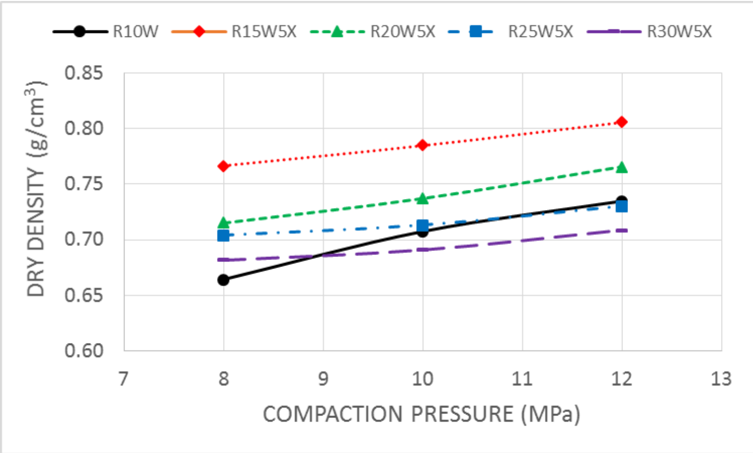
TABLE 1. Briquettes manufacturing parameters and sample codes.

SCG TYPE	MOISTURE CONTENT (%)	BINDER DOSAGE (%)	BINDER TYPE	PRESSURE (MPa)
RAW (R)	15 20 25 30 (W)	5 10	XANTHAN (X) GUAR (G)	8 10 12

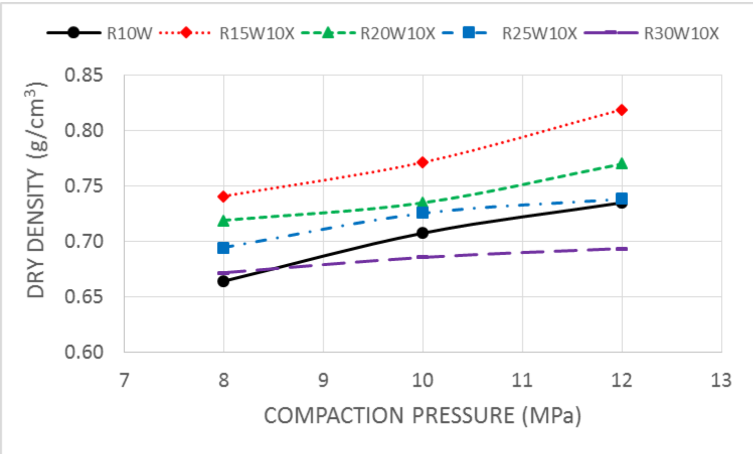
TABLE 2. Chemical characterization of the briquettes combinations and lower heating power.

Analysis	Raw SCG	SCG+5% of xanthan	SCG+10% of xanthan	SCG+5% of guar	SCG+10% of guar
Proximate analysis (% wt.)					
Moisture	2.46	3.84	4.14	3.93	3.96
Volatiles	78.88	76.35	75.85	76.43	76.33
Fixed carbon	18.00	19.01	19.05	19.07	19.20
Ash	0.66	0.81	0.97	0.57	0.52
Ultimate analysis (% wt.)					
N	2.01	1.74	1.72	1.69	1.67
C	57.29	57.23	57.20	55.79	54.50
H	7.52	7.78	7.84	7.48	7.37
S	0.00	0.00	0.00	0.00	0.00
O	33.18	33.25	33.24	35.04	36.46
Lower heating value (J/g)	25399	24450	23503	24398	24321

FIGURE 1. Dry density VS compaction pressure for different additives, dosages and moisture contents. a) 5% of xanthan gum, b) 10% of xanthan gum, c) 5% of guar gum and d) 10% of guar gum.



a)



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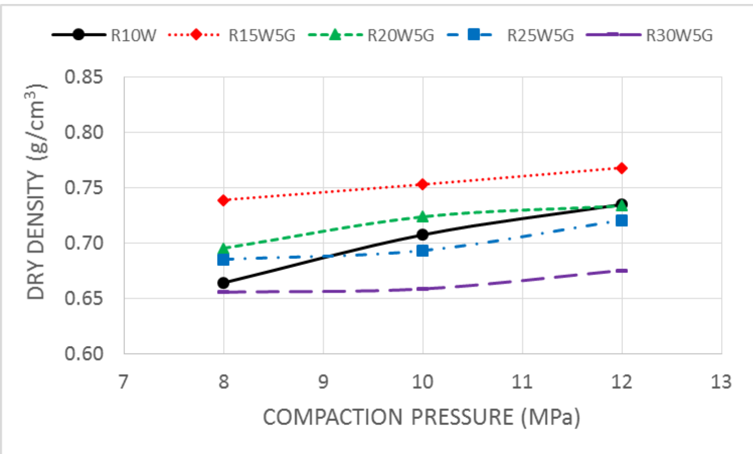

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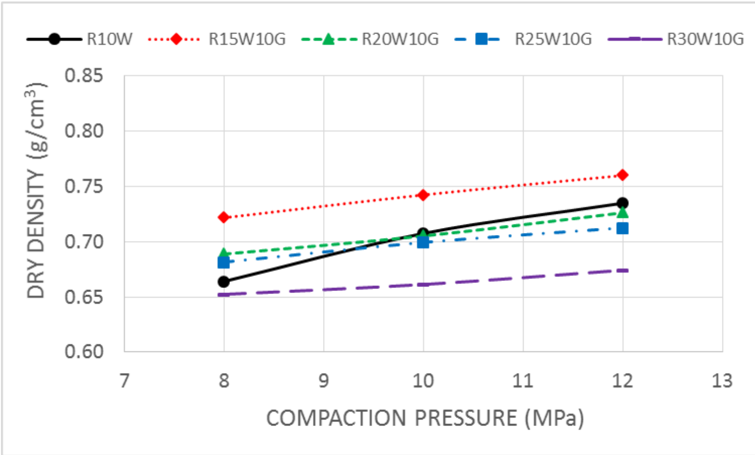
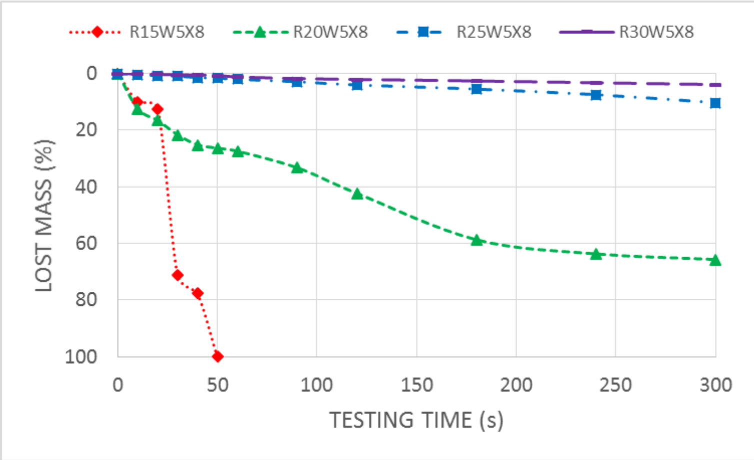


R10W
R15W10G
R20W10G
R25W10G
R30W10G
DRY DENSITY (g/cm3)
0.85
0.80
0.75
0.70
0.65
0.60
7
8
9
10
11
12
13
COMPACTION PRESSURE (MPa)

d)

FIGURE 2. 5% Xanthan gum briquettes results for the durability test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



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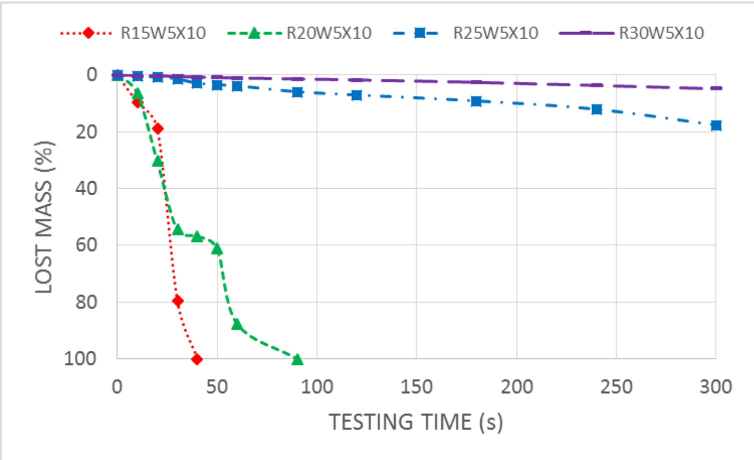

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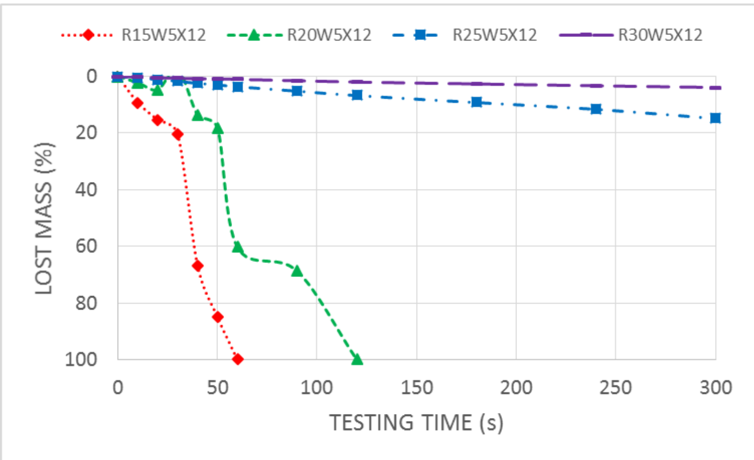
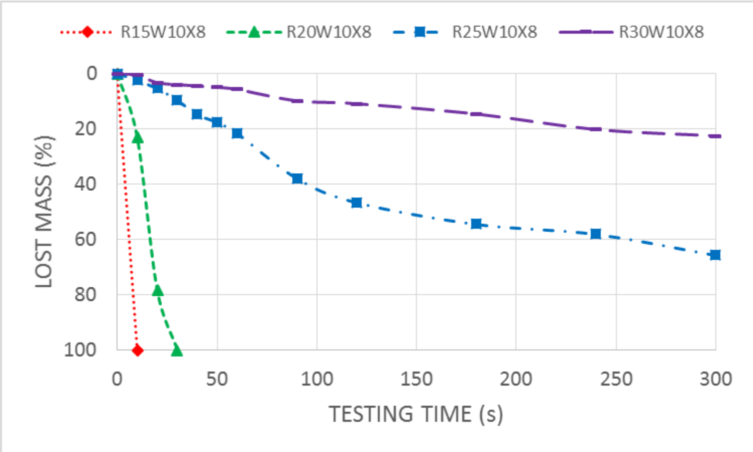


c)

FIGURE 3. 10% Xanthan gum briquettes results for the durability test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



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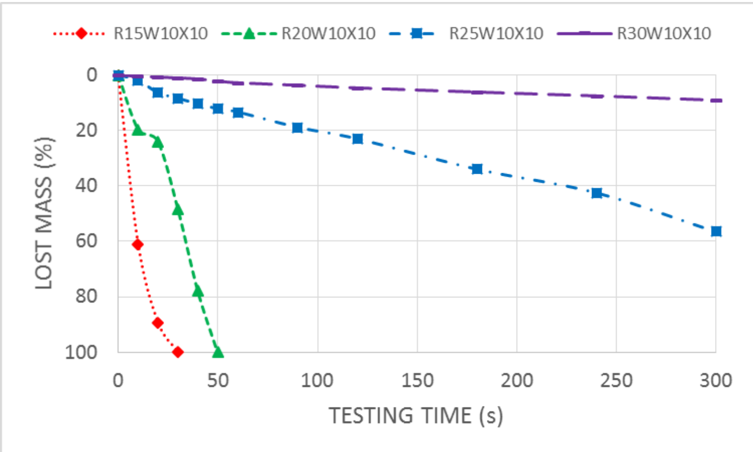

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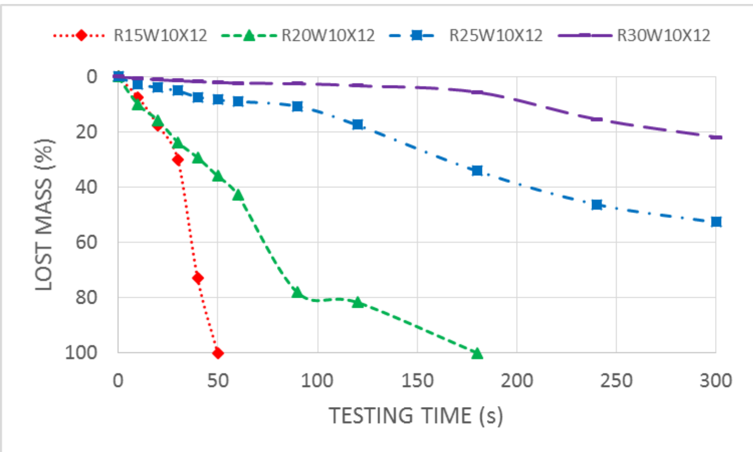
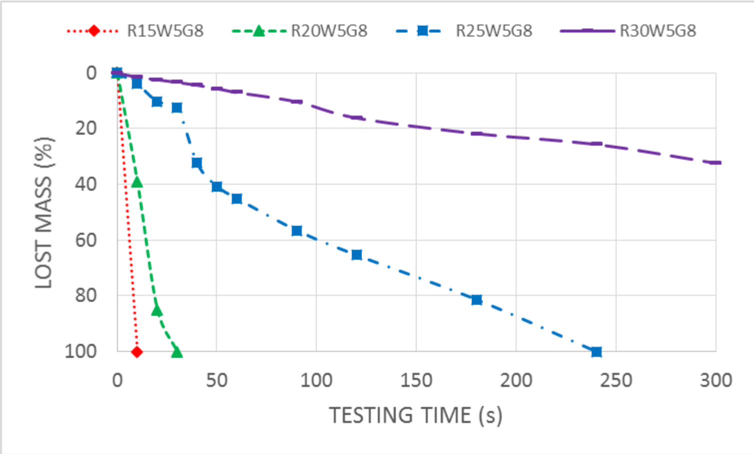
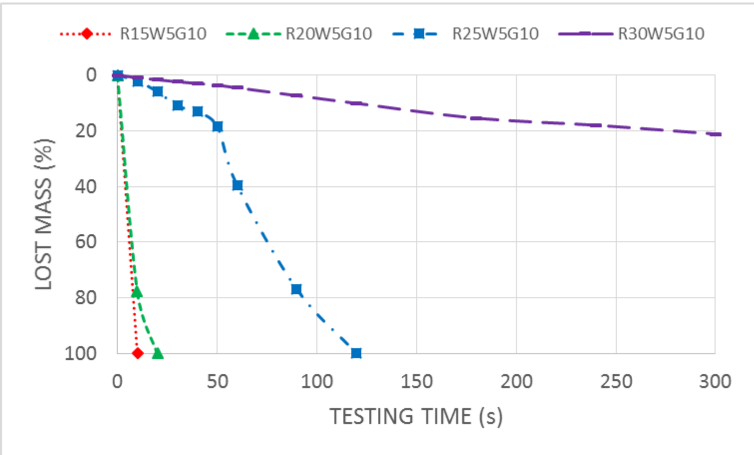


c)

FIGURE 4. 5% Guar gum briquettes results for the durability test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



a)



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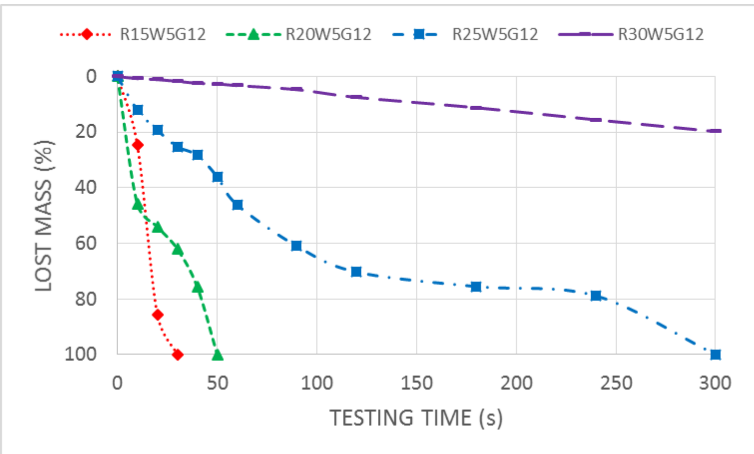
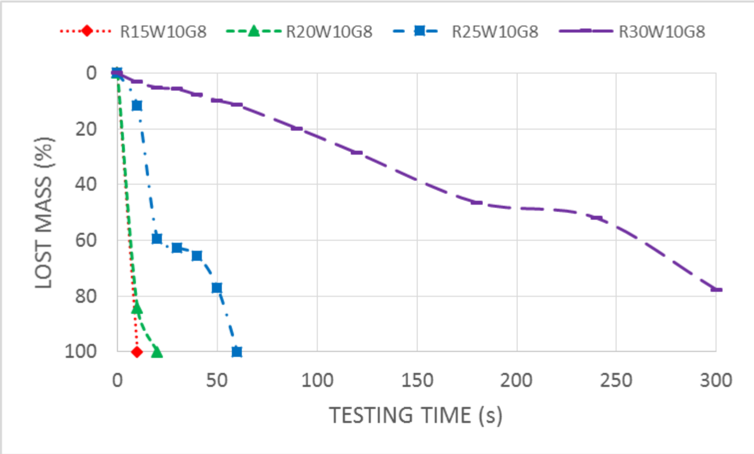
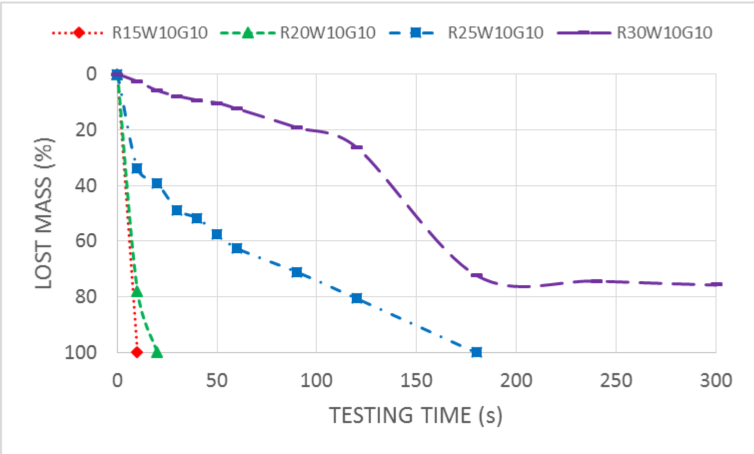


c)

FIGURE 5. 10% Guar gum briquettes results for the durability test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



a)



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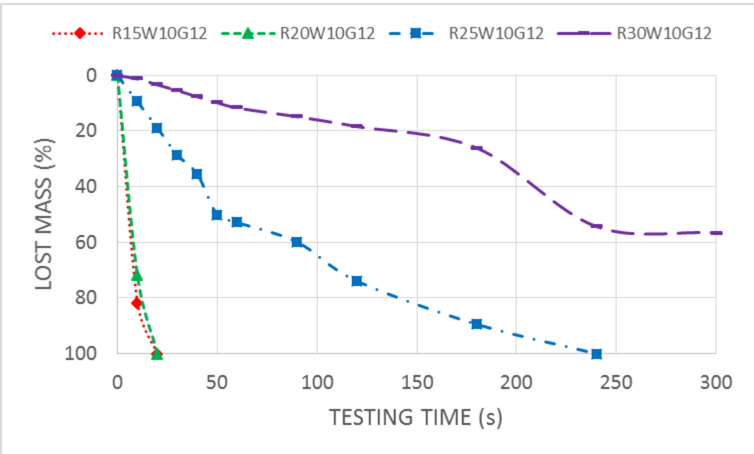
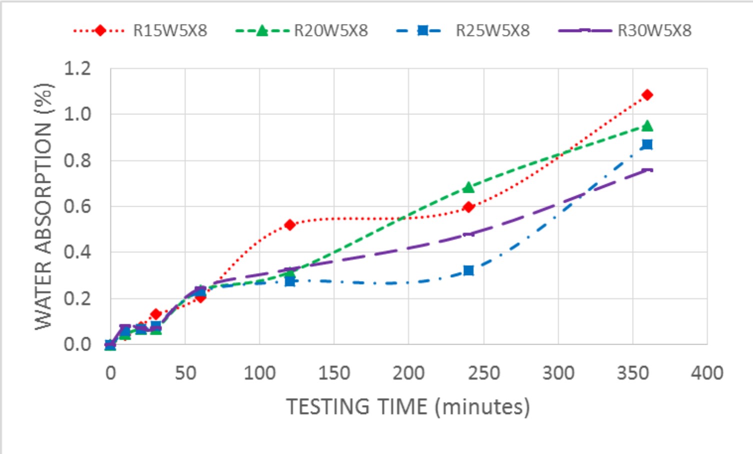
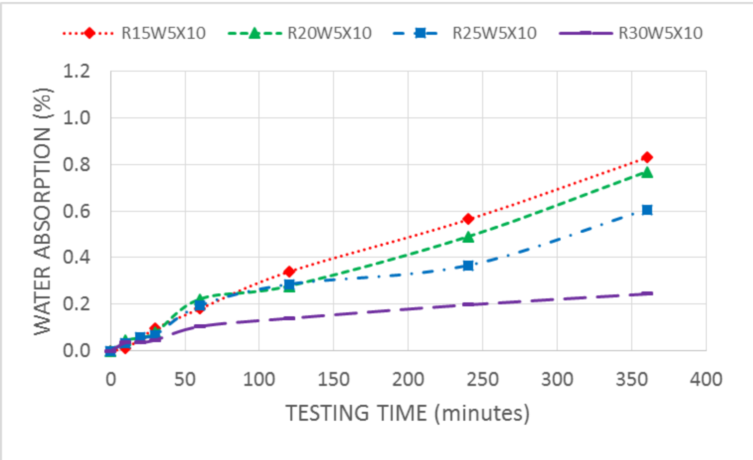


c)

FIGURE 6. 5% Xanthan gum briquettes results for the water absorption test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



a)



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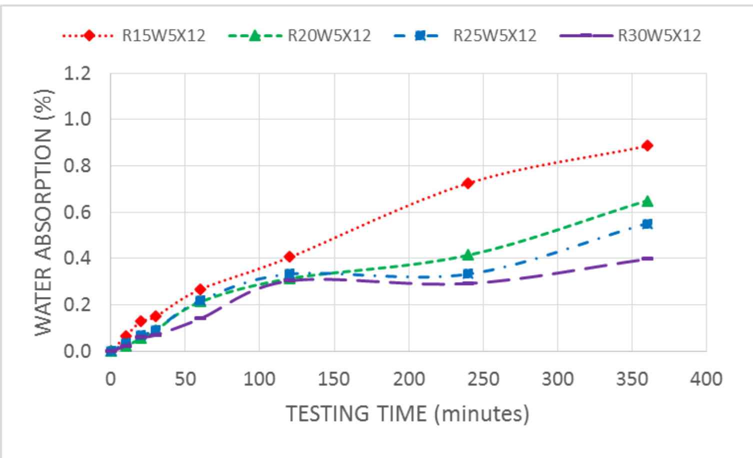
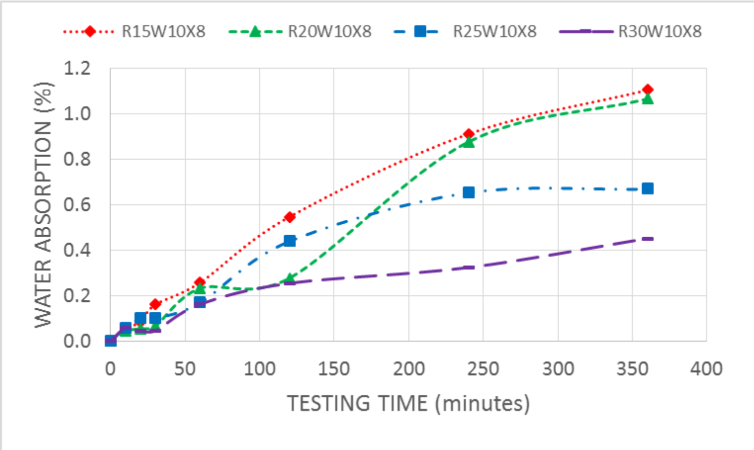
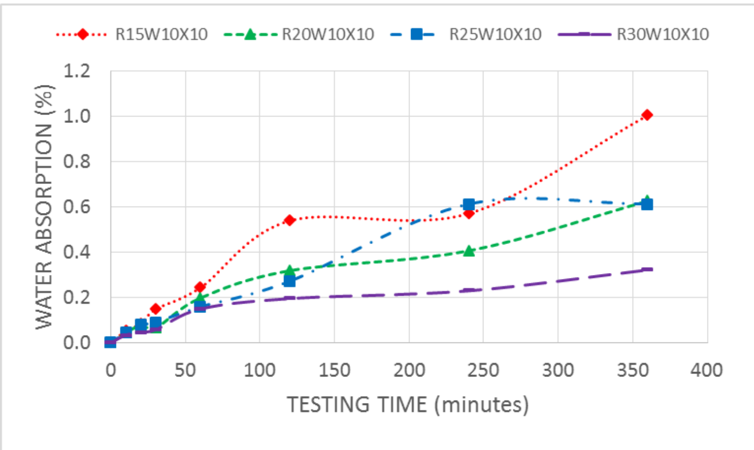


c)

FIGURE 7. 10% Xanthan gum briquettes results for the water absorption test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



a)



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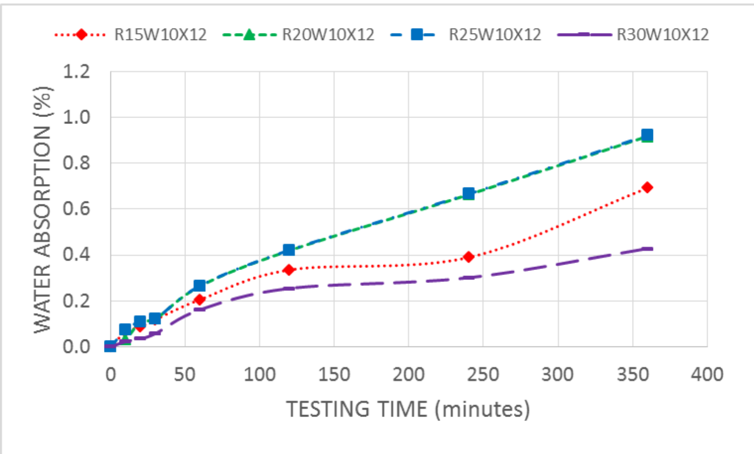
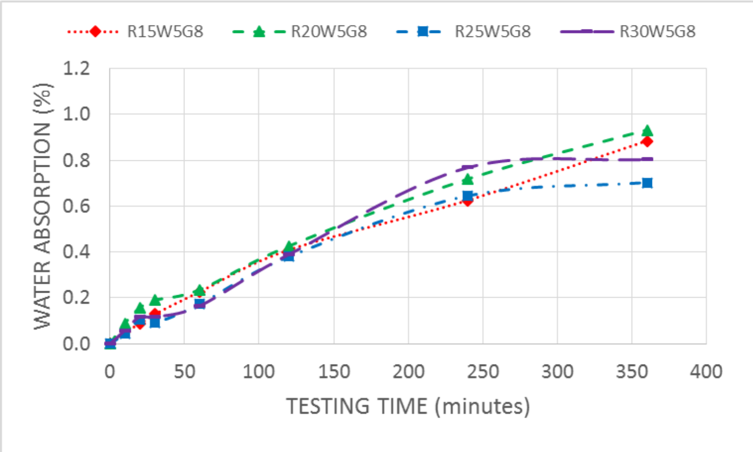
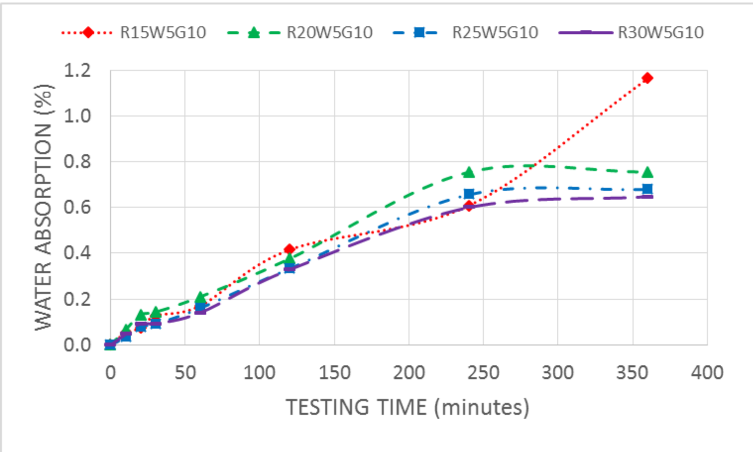


c)

FIGURE 8. 5% Guar gum briquettes results for the water absorption test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



a)



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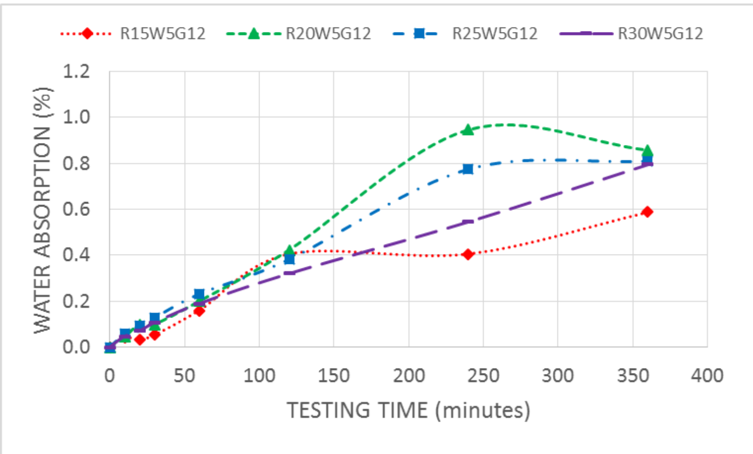
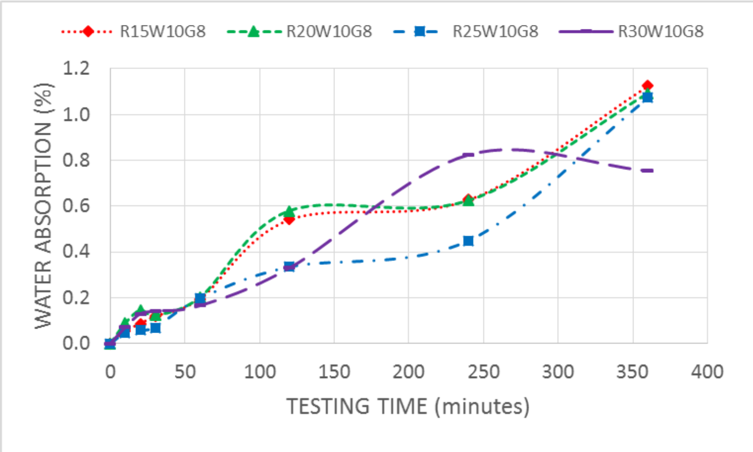
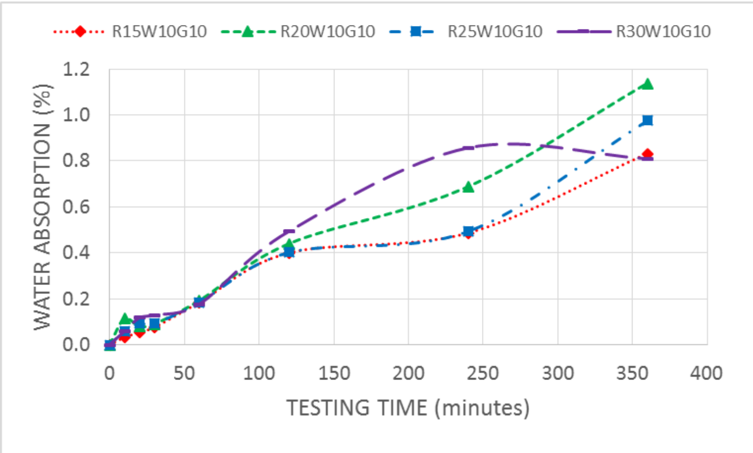


c)

FIGURE 9. 10% Guar gum briquettes results for the water absorption test, manufactured with different compaction energies. a) 8 MPa, b) 10 MPa and c) 12 MPa.



a)



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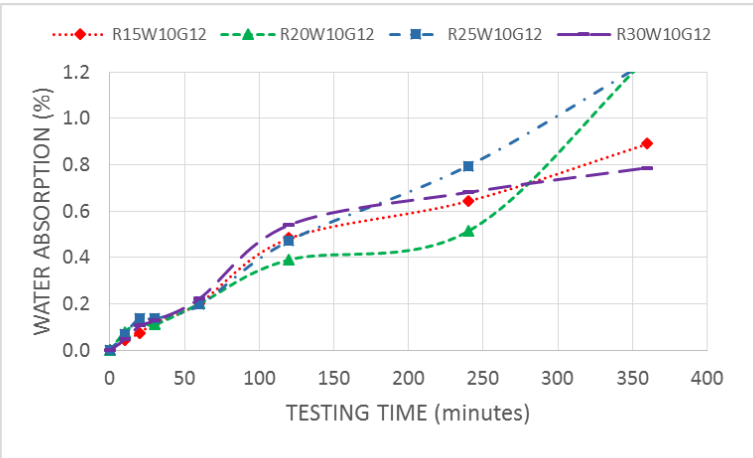
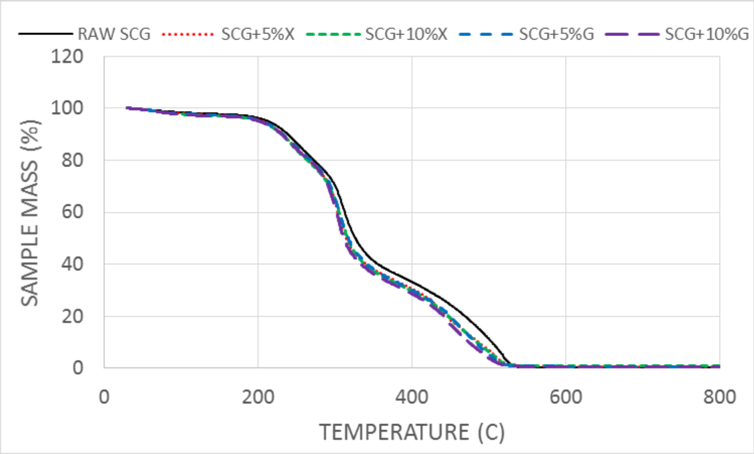
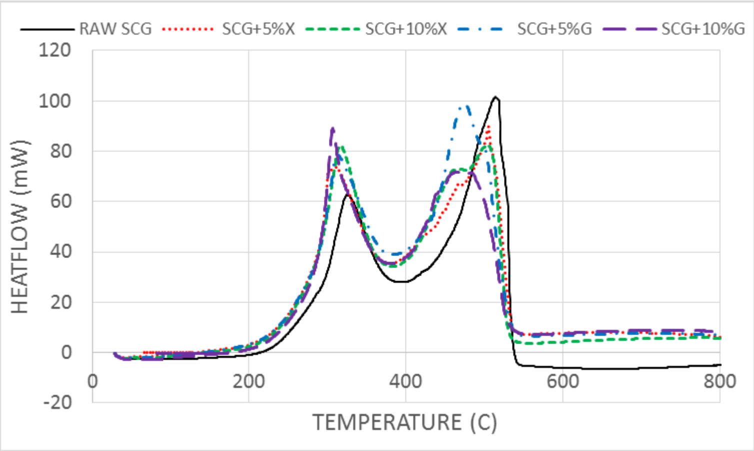


c)

FIGURE 10. Raw SCG and xanthan and guar gum mixes results for the thermogravimetric analysis. a) TG, b) DTA and c) DTG.



a)



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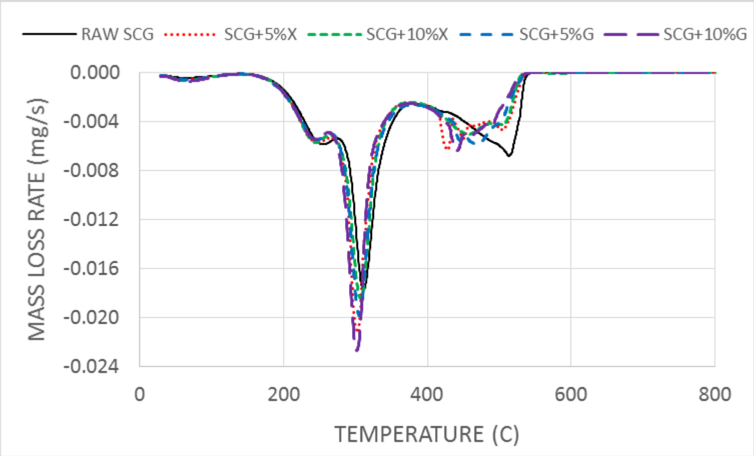

c)