COMPRESSION AND SPRINGBACK PROPERTIES OF HARDWOOD AND SOFTWOOD PELLETS

Amarnath Dhamodaran and Muhammad T. Afzal *

A multiple linear regression analysis was carried out to predict the length of pellets under compression in the die based on moisture, temperature, pressure, hold time, and their interaction terms. Excellent correlations were obtained in the dependency of the considered parameters on length of compressed material inside the die. Springback characteristics based on axial changes after the compaction process were analyzed. The expansion for hardwood pellets (16.28%) was found to be lowest at particle size 0.150 to 0.300 mm with 8% moisture (w.b), 60 ^{o}C, 139.3 MPa pressure, and a hold time of 15S. The expansion for softwood pellets (20.56%) was lowest with particle size 0.300 to 0.425 mm, at 8% moisture (w.b), 70 ^{o}C, 159.2 MPa, and a hold time of 30S.

Keywords: Biomass pellets; Densification; Springback effect; Expansion; Bioenergy; Renewable energy; MLR modeling

*Contact information: Department of Mechanical Engineering, University of New Brunswick, P. O. Box 4400, 15 Dineen drive, Fredericton, New Brunswick, E3B5A3 *Corresponding author: mafzal @unb.ca*

INTRODUCTION

Densified biomass is rapidly becoming an important source of renewable energy for industrial and domestic heating purposes. It is also used as animal bedding and assists in absorbing animal waste and oil spillage. Woody biomass (*e.g.*, sawdust from mills) is widely used in the production of pellets. Densification of raw material can improve transport, storage, and handling characteristics. It can increase the bulk density of the biomass from an initial bulk density of 140 to 200 kgm^{-3} to a final bulk density of 700 to 1020 kgm^{-3} (Mani *et al.* 2002). Densification also helps to overcome other disadvantages such as high moisture content and irregular shape and sizes of biomass. The pelletizing process still has a large inbuilt variability that sometimes leads to substantially lower pellet production rates and variability in pellet quality (Larsson 2008). Therefore, a lab-scale well-controlled designed experiment is required to get credible information about the factors influencing the process.

Expansion in the axial and/or radial dimensions of a compacted granular/powder material when the applied pressure is removed is called the springback effect. Release of elastic energy stored in the material during the compaction process causes this springback behaviour. Thermoplastic material can react to an applied pressure either elastically, when the material is below the glass transition temperature, or viscoelastically, when near or above the glass transition temperature, during the compaction process. Some degree of residual stress appears in the form of springback during the decompacting stage or the ejection of an object from a die. Springback due to elastic recovery in fibrous materials after the densification process considerably increases the overall dimensions of the densified biomass due to expansion that happens during decompacting and the ejection stage. Even though a high amount of densification is obtained during compression of biomass, expansion occurs after the compressive load is released and the pellets are extruded from the die which reduces the overall bulk density. In order to acquire a better understanding of the densification process, a study based on the role of compression characteristics and springback effect in pellet formation phenomena is of considerable importance. This study deals with lab-scale experiments and modeling to describe the behavior of biomass compaction and springback characteristics based on expansion in pellets.

OBJECTIVES

The objectives of this study were as follows:

- Produce pellets using ground material from selected maple hardwood and white spruce softwood species.
- Predict the length of pellets under compressive load based on material and process parameters through multiple linear regression modelling.
- Analyse the springback behaviour based on expansion of pellet length under compression by assuming that the compacted materials have a uniform density and a dimensional homogeneity and focus mainly on axial changes after the compacting process.

Biomass Densification

During the initial stages of compression, particles rearrange themselves under low pressure to form close packing, and the air located in the interstices of the bulk material is removed. During this phase, the particles retain most of their properties, although energy is dissipated due to inter-particle and particle-to-wall friction. The inter-molecular attractive forces during densification include hydrogen bonds and van der Waals forces, of which the latter is said to be a major contributor to attractive forces between solid particles. Kaliyan and Morey (2006) report that with a significant increase in particle size, these forces decrease. During the densification process, the capillary pressure due to the moisture content and interfacial forces create strong bonds, which are temporary, as they disappear once the liquid evaporates. But still, these bonds are essential to the development of cohesive forces. According to Rumpf (1962), cohesive strength of the agglomerate is attributed to the forces exerted by the pendular bridges and capillary suction pressure. Adhesion occurs when dissimilar molecules are attracted to each other, whereas cohesion force takes place between two similar molecules. Viscous binders increase the adhesive and cohesive forces, which are very similar to solid bridges during the compaction process (Grover and Mishra 1996). Solid bridges are the major contributors towards the durability of the pellets. Usually solid bridges are formed at elevated temperature and pressure. The melting of constituents at elevated temperatures promotes molecular diffusion, and when the densified product cools, the melted constituents solidify, forming solid bridges (Tabil 1996; Manickam *et al.* 2006). Preheating the raw material has been shown to lower the work and pressure of compression, likely as an effect of thermal softening of the fibers (Reed *et al* 1980). In addition, the temperature determines the phase behavior of polymers present in the biomass. It is known that the lignin part of the cell wall undergoes a glass transition at temperatures in the neighborhood of 60 °C, depending upon the moisture content and the specific material (Irvine 1984). Above the glass transition temperature, the lignin is more flexible and, hence, it might more effectively take part in the interactions between the cells. Mechanical interlocking of particles may occur during the agitation and compression of fibrous, flat-shaped, and bulky particles (Ghebre-Sellassie 1989; Pietsch

2002; Manickam *et al.* 2006). Even though it is said to be a minor contributor to pellet strength, it can provide sufficient mechanical strength to resist the disruptive forces caused by elastic recovery following compression (Gray 1968).

Densification Variables

Feedstock properties and process variables are the two kinds of densification variables that are considered to have major impact on the quality of pellets. The feedstock properties consist of chemical constituents of the feedstock, which largely depend on the origin of species and geographical location of the pellet mill, along with pre-processing like particle size, moisture content, and pre-heating. Feedstocks are brought in mostly from within the vicinity of the pellet mill to keep the cost in check, as loosely packed unprocessed material takes up a lot of space. The chemical constituents of feedstock, which acts as binders during the formation of bonds during compaction and cooling, differ from one species to another. An investigation by Lehitkangas (2000) explained the role of lignin content in the pellets durability. Table 1 shows the constituents of selected feedstock with white spruce having higher lignin content than maple hardwood. Also, torrefaction and steam addition can play major roles in the densification process (Bergman 2005). Parameters that influence the biomass densification process are pressure, die speed, hold time, die wall friction, temperature, and die geometry (Kaliyan 2009; Larsson 2008). These variables are said to have a strong relation with the major quality parameters such as strength and durability, which decide the market value and quality of the pellet.

Table 1. Chemical Composition of Raw Materials (Sjöström 1993)

Feedstock	Lignin, %	Cellulose, %	Pentason, %	Extractives, %	Ash, %
Hard Maple	22.8	44.5	17.1	2.5	5.2
White Spruce	27.8	42.1	12.1	2.3	0.6

Post-Production Conditions

Post-production conditions play a significant role in both strength and durability values. Kaliyan and Morey (2006) identified that the timing of measurement in addition to cooling and drying conditions impacts durability. Mohsenin and Zaske (1976) observed that the timing of abrasion testing was indirectly related to durability values. The durability of the densified products tested immediately after production was higher than that obtained 45 minutes later. This was attributed to the negative impact of drying and expansion of the pellets. Payne (1978) observed that the timing of measurement significantly impacted the hardness values of dairy feed pellets when measured immediately after production and 24 hours later. Compressive resistance increased from 78.5 to 131.4 N with additional curing. The author attributed this to the formation of solid bridges as the pellets cooled. Kaliyan and Morey (2006) distinguished between the “green” strength and the cured strength of pellets. Green strength refers to a measurement carried out immediately after production, and cured strength refers to testing conducted approximately one week later. Timing of measurement affects both durability and compressive resistance measurements. Kaliyan and Morey (2009) also pointed out the role of temperature on the mean expansion in volume of densified biomass where corn stover and switchgrass from 3 mm screen size with a moisture content of 8.7% expanded by 12.2% and 15.6%, respectively at 25^{o}C, while their expansion was a mere 0.3% and 1.2%, respectively at 75^{o}C. Their durability values of 96.8% and 62.9% were also the highest, which shows the relation between the role of temperature on the mean expansion in volume.

EXPERIMENTAL

Preparation of Feedstock

In order to differentiate the feedstock into an accountable number of groups, the species were classified as hardwood, softwood, or grass for study purposes (Stelte *et al.* 2011). White spruce softwood and maple hardwood were used in this study. Biomass material was obtained in the form of wood chips. It was first bone dried in a conventional oven at 105^{o}C for 24 hours. The bone-dried feedstock was then ground with a 1 hp model 4 Thomas-Wiley mill (Thomas Scientific., Swedesboro, NJ, USA). The ground feedstock then was passed through a sieve test to differentiate different particle sizes of 0.300 mm to 0.425 mm and 0.150 to 0.300 mm. Based on research conducted by Arshadi (2008) that revealed a moisture content of about 8 to 10% as optimum for pellets, known moisture of 8 and 10% were added to the feedstock samples, and they were kept in an air-tight container for 48 hours for even distribution of moisture before the pelleting process.

Experimentation Setup

The densification experiments were carried out using a uniaxial single piston–cylinder assembly, which was built in-house for research purposes (Fig. 1). The cylinder had a diameter of 8 mm and length of 202 mm. The apparatus was constructed in such a way that it could be mounted directly onto an Instron universal testing machine (Model 3367; Instron Corporation, Canton, MA, USA), which was used for applying the load. The die itself was wrapped with two, 300 W heating elements and covered by insulation materials to create required heating around the die. The temperature settings were controlled by a Fuzy pro F16 (HCS Ltd., ON, Canada) Proportional Integral Derivative (PID) controller.

Experiment Procedure and Conditions

In order to evaluate the role of hold time on expansion in pellets, three runs of 0, 15, and 30 seconds of hold time were conducted. The purpose is to point out the application of springback behaviour in a practical design problem, where hold-time affects the quality of the compressed material. Two different loads of 139.26 MPa (± 3 MPa) and 159.16 MPa (± 3 MPa) were applied for producing pellets at a die speed of 0.43 mm s^{-1}. Two temperatures of 60^{o}C (± 1^{o}C) and 70^{o}C (± 1^{o}C) were selected to study the role of temperature. Tests were replicated three times for the following combinations (2 pressures x 2 particle size x 2 moisture content x 2 temperature x 3 hold time). The mean of all three replications are tabulated and analyzed. The pre-heating temperature of desired value was obtained with the help of heating elements and the PID controller. The weight of material loaded into the die and the weight of the compacted biomass were recorded, along with their dimensions before (length of pellet in the die under compressive load) and after extrusion (length of ejected pellet). The length of pellet in die under compression was calculated by measuring the length of piston outside the die at the end of compression. Length of pellets were measured after a week's time after the pellets were allowed to cure in air tight bags at room temperature and the means were tabulated.

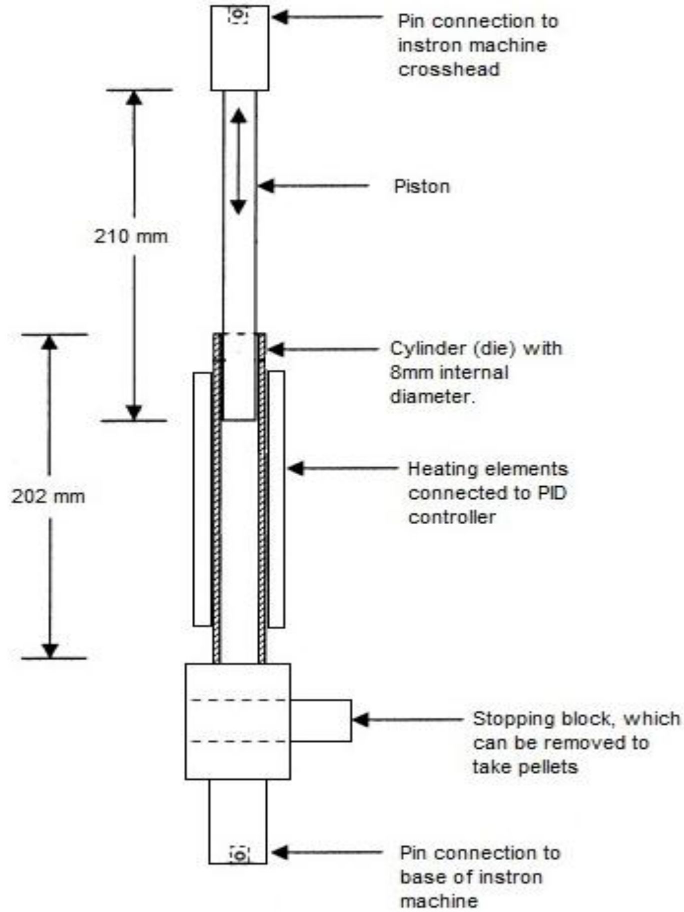

Fig. 1. Experimental set up of uniaxial single piston–cylinder assembly for pelletization

The compression and springback characteristics of experimental pellets were studied based on three different stages. While the conditions under compression loading were noted first, data for pellets extruded from the die immediately and after one week were also noted; these two measurements were differentiated as green and cured pellets (Kaliyan and Morey 2009). The mass of feedstock used in making hardwood pellets for each run was 1.16 grams (moisture was mixed to feedstock 48 hours before the experiments were conducted and stored in air tight bags and the weighed before each run) with bulk densities ranging between 265 and 295 Kg m^{-3}, while that of softwood was 1.21 g with bulk densities ranging between 152 to 162 Kg m^{-3} (Table A1) based on particle size and moisture content. The diameter of the die used for making pellets was 8 mm in size.

RESULTS AND DISCUSSION

Multiple linear regression (MLR) modeling was carried out to predict the densification of biomass based on feedstock and process variables. Data sets were separated based on feedstock and their particle size. Pressure, moisture content, temperature, and hold time were considered as independent variables to define the length of pellets under compression, which was considered as a dependent variable. Analysis of variance for experimental data was carried out with interaction terms of up to three factors to find the significance of feedstock and process variables on densification of biomass. The significance (p) values are shown (Table 2) for hardwood and softwood pellets of particle size 0.150 to 0.300 mm and 0.300 to 0.425 mm.

Table 2. Variance Analysis of Main Factors and Interaction Terms

Source	Maple Hardwood (P.S 0.150 to 0.300mm)		Maple Hardwood (P.S 0.300 to 0.425mm)		White Spruce Softwood (P.S 0.150 to 0.300mm)		White Spruce Softwood (P.S 0.300 to 0.425mm)	
	DOF	p-value	DOF	p-value	DOF	p-value	DOF	p-value
Moisture content	1	0	1	0	1	0	1	0
Temperature	1	0	1	0	1	0	1	0
Pressure	1	0	1	0	1	0	1	0.331*
Hold time	2	0	2	0	2	0	2	0
Moisture content * Temperature	1	0.001	1	0	1	0.006	1	NA
Moisture content * Pressure	NA	NA	1	0.03	NA	NA	NA	NA
Moisture content * Hold time	NA	NA	NA	NA	NA	NA	1	0.048
Error	17	NA	16	NA	17	NA	15	NA
SD	0.38		0.33		0.51		0.44	
R^2	95.4		93.2		98.9		97.8	

Test sample = 24 sets/species/Particle Size
Sources are reported only for p < 0.05.
* Independent variable with p > 0.05.

Multiple linear regression (MLR) analysis of the significant variables and interaction terms was carried out to correlate the parameters and the length of the pellet under compressive load.

MLR models obtained for both the species with different particle sizes were as follows:

Hardwood pellets:

$F_{5, 18} = 71.42$, $p < 0.0005$ for hardwood pellets with particle size 0.150 to 0.300 mm

$F_{6, 17} = 38.81$, $p < 0.0005$ for hardwood pellets with particle size 0.300 to 0.425 mm

Softwood pellets:

$F_{4, 19} = 247.50$, $p < 0.0005$ for softwood pellets with particle size 0.150 to 0.300 mm

$F_{4, 19} = 139.55$, $p < 0.0005$ for softwood pellets with particle size 0.300 to 0.425 mm

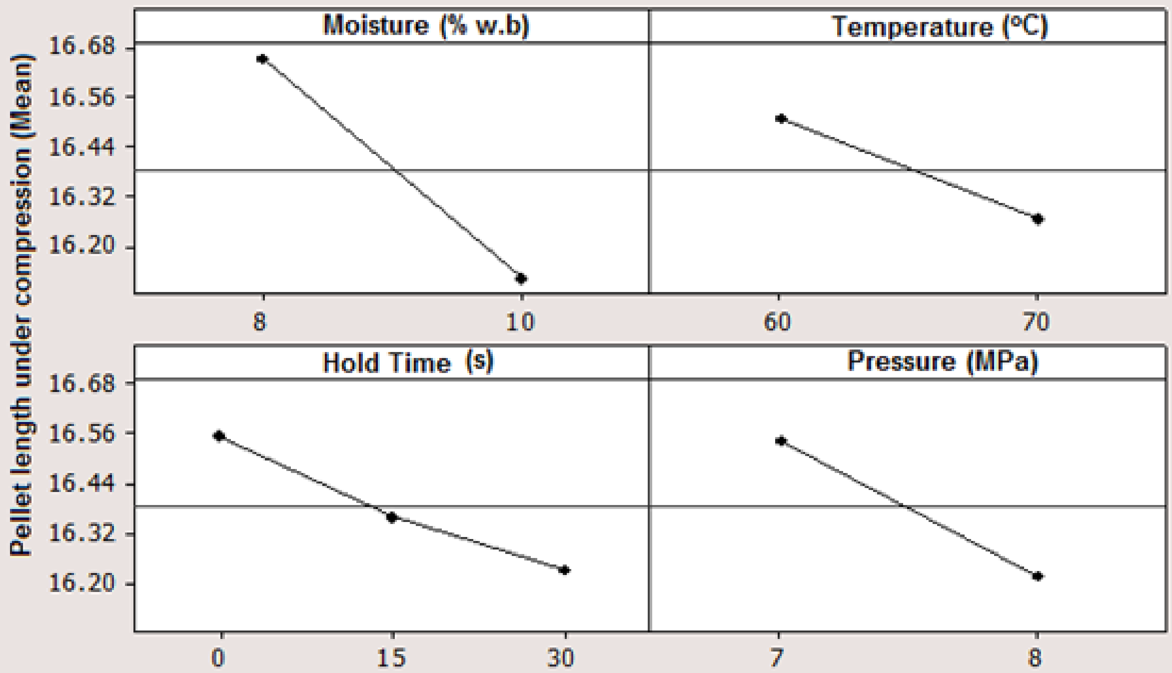

Fig. 2a. Main effects plot for length of pellet in die under compression (fitted means) for Hardwood with particle size 0.300 to 0.150mm.

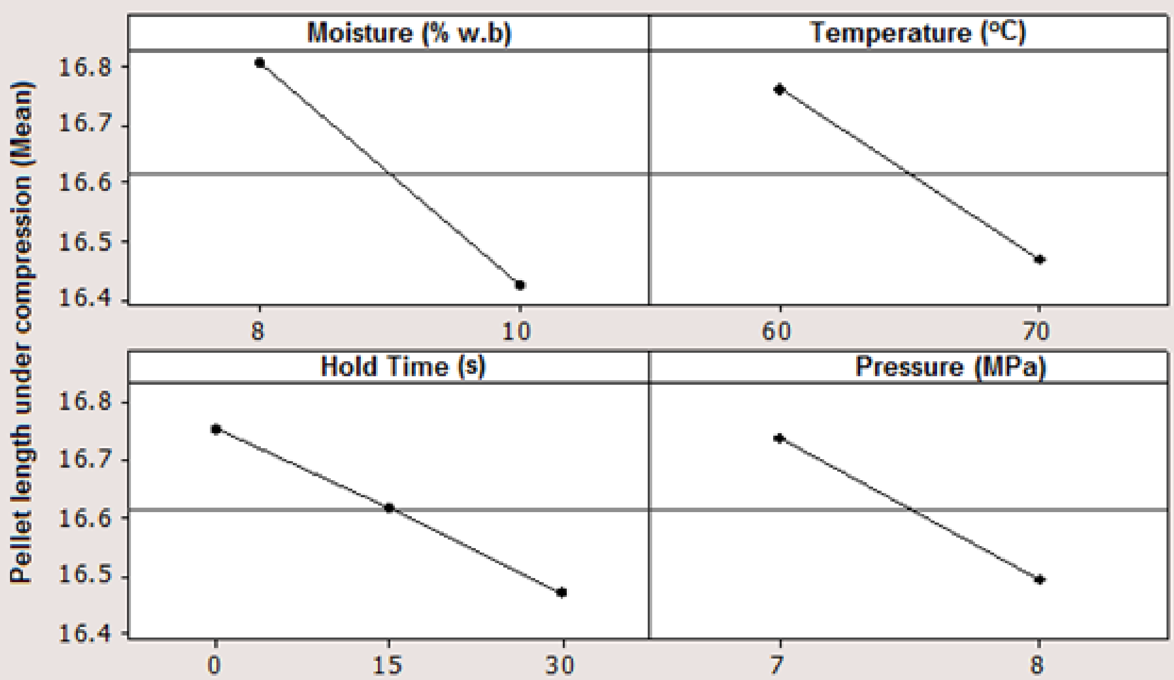

Fig. 2b. Main effects plot for length of pellet in die under compression (fitted means) for Hardwood with particle size 0.425 to 0.300mm.

Fig. 2a & b. Main effects plot for length of pellet in die under compression (fitted means) for hardwood with particle size 0.150 to 0.300 mm and 0.300 to 0.425 mm, respectively

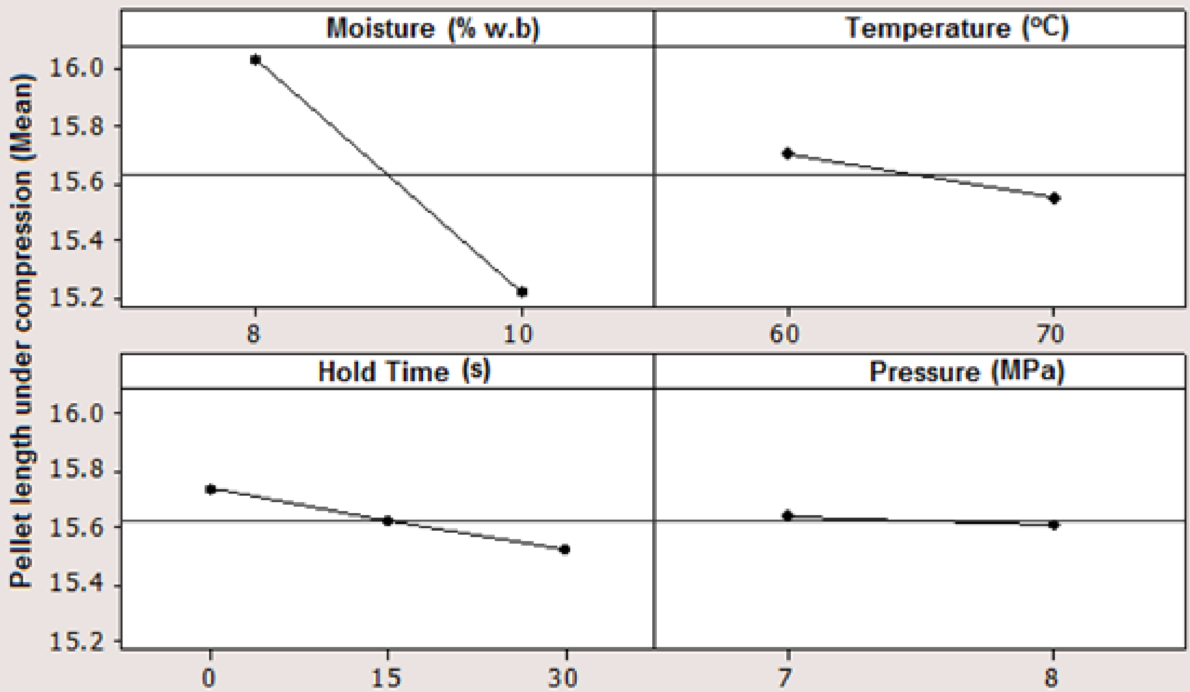

Fig. 3a. Main effects plot for length of pellet in die under compression (fitted means) for Softwood with particle size 0.300 to 0.150mm.

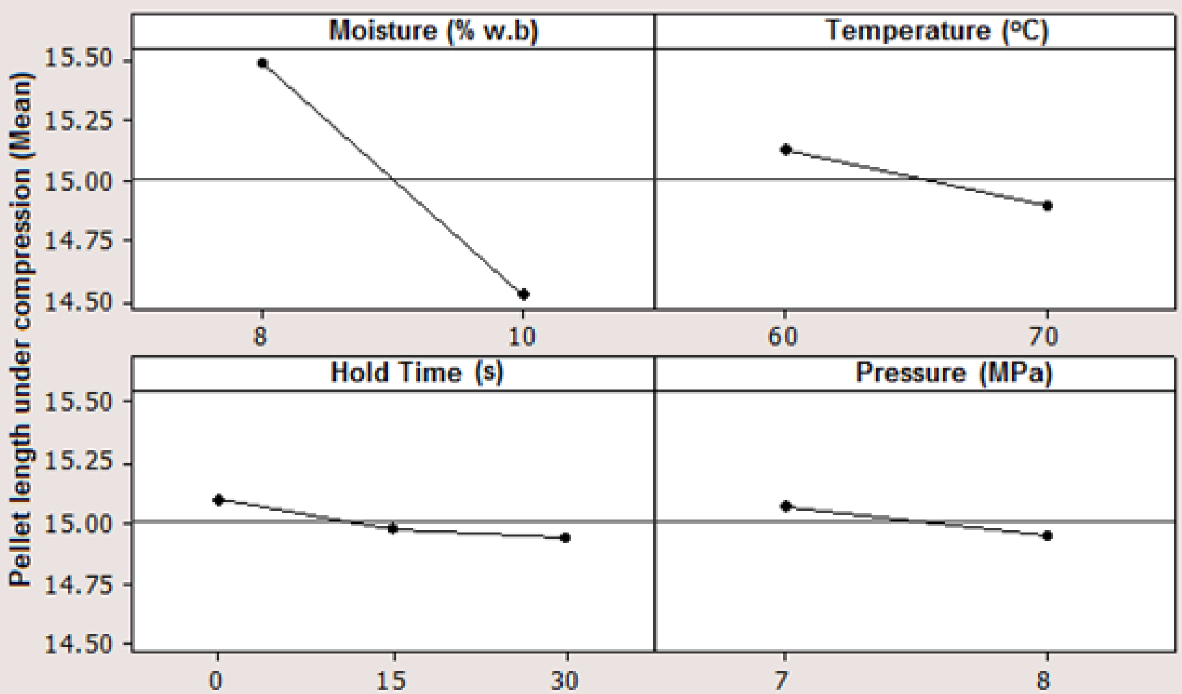

Fig. 3b. Main effects plot for length of pellet in die under compression (fitted means) for Softwood with particle size 0.425 to 0.300mm.

Fig. 3a & b. Main effects plot for length of pellet in die under compression (fitted means) for softwood with particle size 0.150 to 0.300 mm and 0.300 to 0.425 mm, respectively

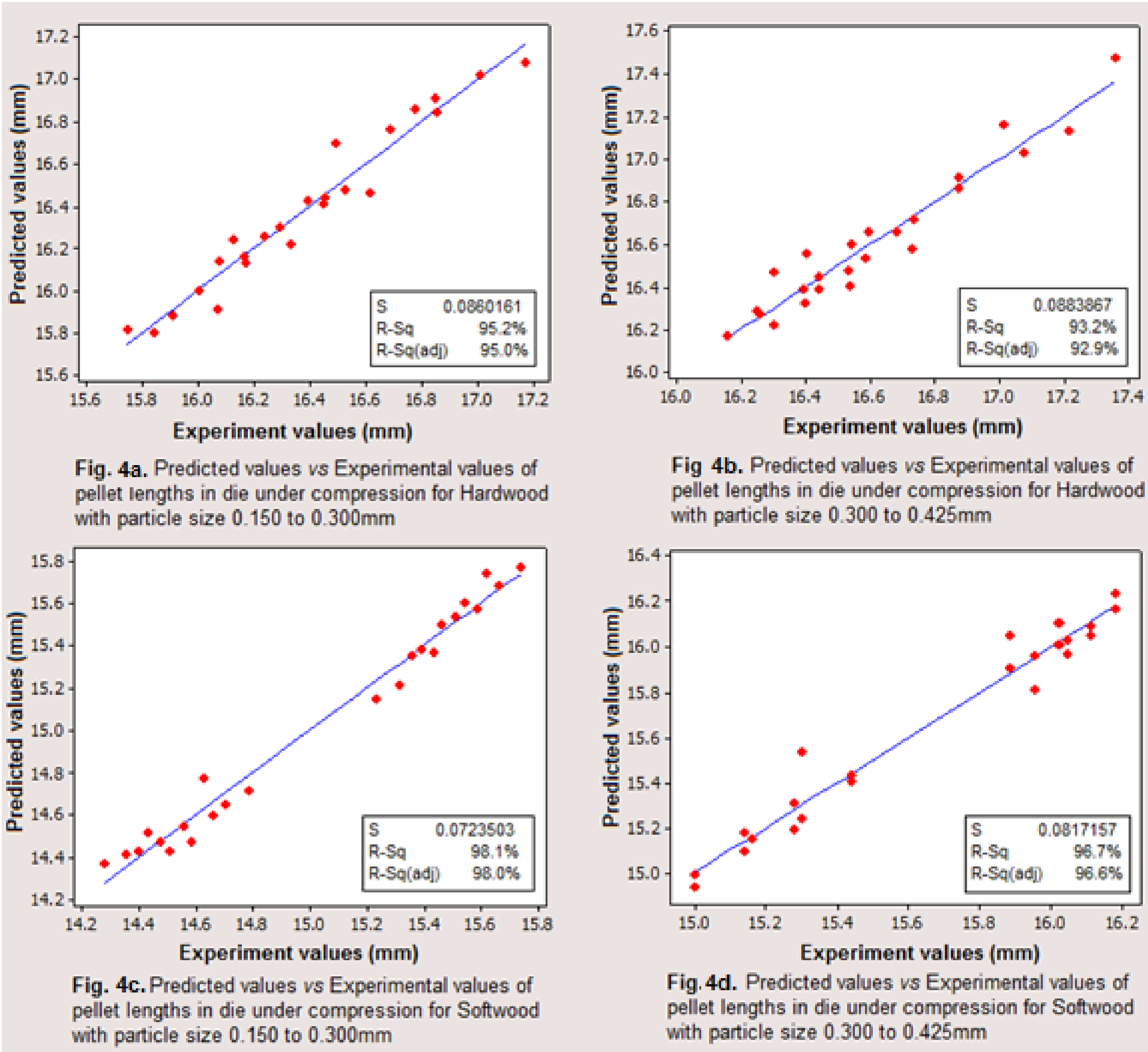

Fig. 4a. Predicted values *vs* Experimental values of pellet lengths in die under compression for Hardwood with particle size 0.150 to 0.300mm

Fig 4b. Predicted values *vs* Experimental values of pellet lengths in die under compression for Hardwood with particle size 0.300 to 0.425mm

Fig. 4c. Predicted values *vs* Experimental values of pellet lengths in die under compression for Softwood with particle size 0.150 to 0.300mm

Fig. 4d. Predicted values *vs* Experimental values of pellet lengths in die under compression for Softwood with particle size 0.300 to 0.425mm

Fig. 4. Predicted values *vs.* experimental values of pellet lengths in die under compression for hardwood and softwood

The relation between the independent variables along with interaction terms and a dependent variable using the observed data with multiple linear regressions was set as follows,

$$L_{fp} = \beta_h H + \beta_p P + \beta_m M + \beta_t T + \beta_I I$$

where the dependent variable L_{fp} is the length of the pellet under compression (mm) for a given particle size; H is hold time (seconds); P is pressure (MPa); M is moisture (% wet basis); T is temperature (^{o}C), and I is the interaction term up to three factors. β_h, $\beta_p P$, $\beta_m M$, $\beta_t T$, and $\beta_I I$ are partial regression coefficients.

For hardwood pellets of particle size 0.150 to 0.300 mm,

$$L_{fp} = 31.8–1.25M–0.16T-0.326P–0.011H+0.015MT. \qquad (R^2 = 0.952)$$

For hardwood pellets of particle size 0.300 to 0.425 mm,

$$L_{fp} = 40.2–2.19M+0.201T-1.15P-0.009H+0.019MT+0.101MP. \qquad (R^2 = 0.932)$$

For softwood pellets of particle size 0.150 to 0.300 mm,

$$L_{fp} = 21.8-0.479M-0.023T.0.123P-0.005H. \qquad (R^2 = 0.981)$$

For softwood pellets of particle size 0.300 to 0.425 mm,

$$L_{fp} = 20.1–0.372M-0.016T+0.014H-0.002MH. \qquad (R^2 = 0.967)$$

The predicted values obtained using MLR modeling for length of pellet in die under compression were plotted against their respective experimental values as shown in Figs. 4a, 4b, 4c, and 4d, which indicates excellent prediction capacity of the model with R^2 values of 0.952 (95%) and 0.932 (93%) for hardwood pellets of particle size 0.150 to 0.300 mm and 0.300 to 0.425 mm, respectively. It also indicates that the process parameters could be used to analyze the expansion in pellet length. A sig (p) value of zero for the model shows that the independent values were able to predict the dependent value. An MLR analysis in the similar fashion for pellets of particle size 0.150 to 0.300 mm and 0.300 to 0.425 mm from softwood gave R^2 values of 0.981 (98%) and 0.961 (96%), respectively, with sig (p) value being zero.

The effect of process parameters on length of pellet in die under compression can be analyzed using the main effects plot shown in Figs. 2a & b for hardwood and 3a & b for softwood with their selected parameters. These plots show the effect of each independent variable on length of pellet in die under compressive load. It can be seen from Figs. 1 & 2 that an increase in all four independent parameters played a role in the compression of feedstock to a higher level in hardwood species. Figures 3a & b suggest that an increase in moisture content played a more prominent role than the other three parameters in the analyzed range.

Springback Characteristics

Pellets made from hardwood chips for different compression conditions involved in this study had a diameter of 8.09 to 8.11 mm (Table A1), and there was not much difference in the diameter of the cured pellets comparatively. The unit pellet density ranged from 1061 to 1122 Kg m^{-3} for a compressive load of 139.3 MPa and 159.2 MPa. The length of the pellet under compressive loading ranged from 15.80 to 17.48 mm, while the same for pellets immediately after extrusion ranged from 19.65 to 20.70 mm. Expansion percentage based on the mean of three trials for each case is reported in Fig. 5 for pellets made from hardwood with selected particle size. The mean initial expansion in the length of pellets for the selected parameters with hardwood pellets of particle size 0.300 to 0.425 mm was 21.11% (S.D = 2.18). Hardwood pellets with particle size 0.150 to 0.300 mm had an initial mean expansion of 18.62% (S.D = 1.67) (Table A1). This change in overall dimension of pellet length under compression and extruded pellet is attributed to the concept of springback effect. While a considerable amount of expansion was noted between the feedstock under compression load to newly extruded pellets, the same was not true for the cured pellets, which showed a mean expansion of 0.6% when compared to newly extruded pellets. This can be related to the operating temperatures as observed from work based on corn stover and switchgrass by Kaliyan and Morey (2009).

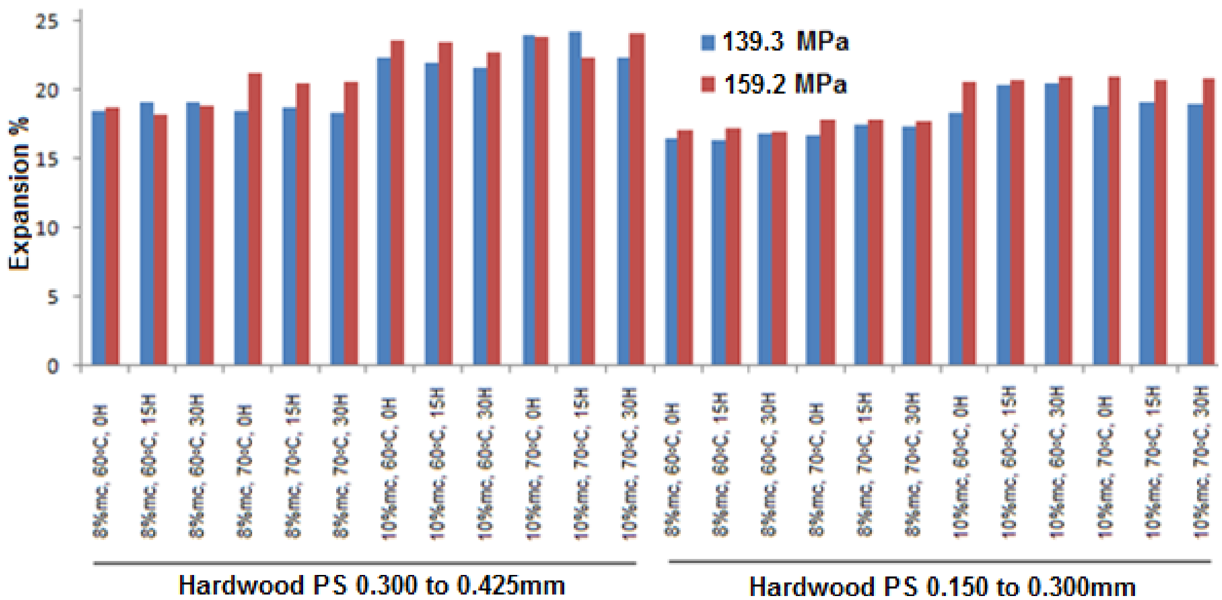

Fig. 5. Expansion in hardwood pellets with particle size 0.300 to 0.425 mm and 0.150 to 0.300 mm (MC – moisture content, H – hold time, PS – particle size)

At similar compression conditions, a feedstock mass of 1.21 grams (Table A1) was required to make pellets from softwood of extruded length ranging between 19.00 and 20.25, while their diameter ranged from 8.08 and 8.11 mm. It was also noted that the bulk density of feedstock from softwood (152 to 162 kg m^{-3}) was considerably lower than that of biomass from hardwood, which in turn increased the die fill area.

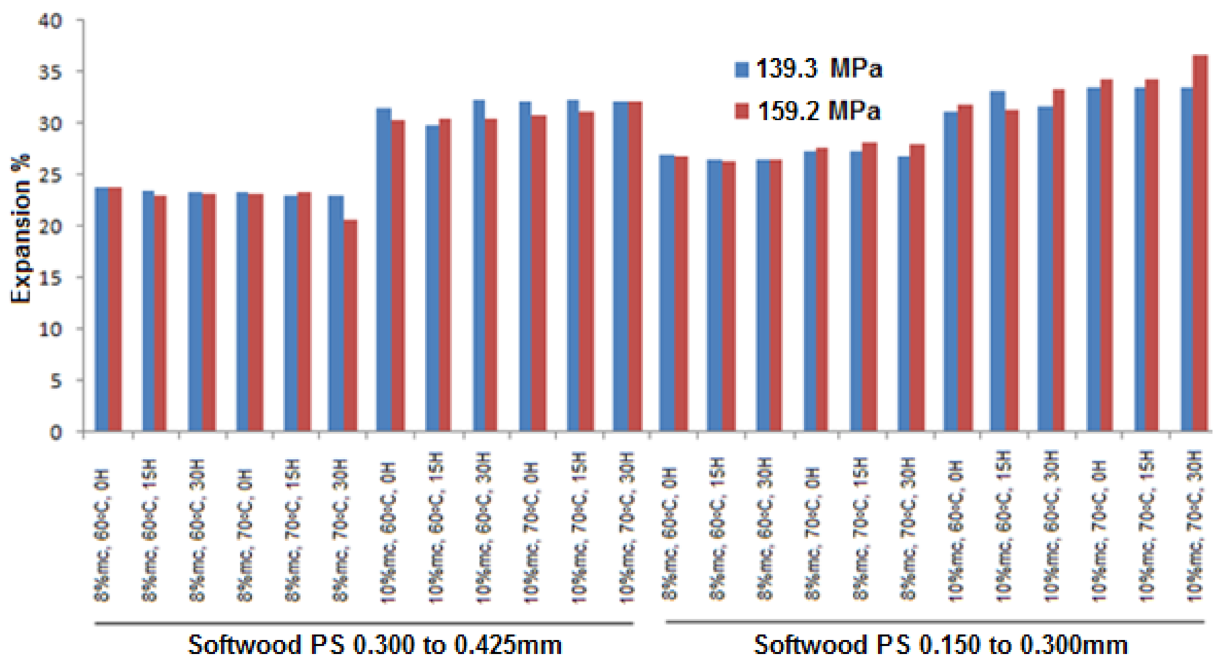

Fig. 6. Expansion in softwood pellets with particle size 0.300 to 0.425 mm and 0.150 to 0.300 mm (MC – moisture content, H – hold time, PS – particle size).

The length of pellets at the end of compressive loading ranged from 14.37 to 16.24 mm. Mean initial elongation in green pellets compared to their respective lengths under loading was 27.15% (S.D = 4.30) for softwood pellets made with particle size 0.300 to 0.425 mm and 30.09% (S.D. = 3.32) for particle size 0.150 to 0.300 mm. Expansion percentage for pellets made of softwood based on mean of three trials for each case is reported in Fig. 6. Unit pellet densities for the selected parameters ranged from 1096 to 1157 Kg m^{-3}.

Expansion in length of green pellets when compared with pellets length under compressive load was lowest for hardwood spices (16.28%) at a particle size of 0.150 to 0.300 mm at a moisture of 8% (w.b), 60 ^oC, 139.3 MPa, and a hold time of 15 sec. The expansion for softwood pellets was lowest (20.56%) with particle size 0.300 to 0.425 mm, at a moisture of 8% (w.b), 70 ^oC, 159.2MPa, and hold time of 30 sec. It was also noted that the average density of pellets made of softwood over the complete process was higher than that of the hardwood, which can be attributed to the presence of higher lignin content (Table 1).

CONCLUSIONS

1. The selected feedstock and process parameters consisting of hold time, pressure, moisture content, and temperature (main factors) along with their interaction terms were able to predict the length of pellet under compressive load for hardwood and softwood pellets with an accuracy between 93% and 98.2%.
2. The study explains the effect of selected individual parameters on the length of pellet under compressive load, and the model helps to understand the compression characteristics in a closed end die in the analyzed range.
3. Springback characteristics based on axial changes after the compaction process, which happens during decompacting and ejection stage from the die, was analysed, and sets of parameters that provide the least expansion were identified. Expansion was lowest for maple hardwood species (16.28%) with particle size 0.150 to 0.300 mm at moisture 8% (w.b), 60 ^oC, 139.3 MPa, and a hold time of 15 sec. Softwood pellets made of white spruce had lowest (20.56%) expansion with particle size 0.300 to 0.425 mm, at moisture 8% (w.b), 70 ^oC, 159.2 MPa, and a hold time of 30sec.

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APPENDIX

Table A1. Compaction Characteristics of Pellets

Hold Time, (s)	Pressure, (MPa)	Moisture Content, (%wb)	Temperature, (°C)	Pellet length in die under compression, (mm) Mean	SD	Extruded pellet length, (mm)	Pellet diameter after extrusion, (mm)	Expansion (length) in extruded pellet, %	Density of extruded pellet, Kg/m³	Cured pellet length, (mm)	Expansion in cured pellet, %	Density of cured pellet, (Kg/m³)
Hardwood pellets, particle size 0.300 to 0.425mm												
0	139.26	8	60	17.48	0.04	20.70	8.11	18.42	1069.25	20.88	0.86	1061.14
15	139.26	8	60	17.13	0.07	20.40	8.10	19.09	1087.18	20.49	0.44	1081.36
30	139.26	8	60	17.03	0.03	20.29	8.09	19.14	1095.68	20.45	0.78	1087.87
(Note: intermediate data was intentionally cut to save space)												
0	159.16	10	70	16.45	0.08	20.38	8.09	23.89	1087.31	20.52	0.68	1072.59
15	159.16	10	70	16.47	0.05	20.14	8.10	22.28	1091.38	20.23	0.44	1082.69
30	159.16	10	70	16.17	0.07	20.06	8.10	24.06	1102.02	20.17	0.55	1089.47
Hardwood pellets, particle size 0.150 to 0.300mm												
0	139.26	8	60	17.08	0.05	20.46	8.10	16.52	1080.86	20.54	0.39	1079.20
15	139.26	8	60	17.02	0.08	20.33	8.10	16.28	1086.24	20.42	0.44	1087.54
30	139.26	8	60	16.84	0.06	20.24	8.10	16.80	1092.22	20.38	0.69	1089.00
(Note: intermediate data was intentionally cut to save space)												
0	159.16	10	70	15.91	0.07	20.14	8.10	21.00	1088.40	20.29	0.74	1071.84
15	159.16	10	70	15.88	0.05	20.04	8.09	20.76	1100.90	20.11	0.35	1091.75
30	159.16	10	70	15.82	0.04	19.97	8.10	20.78	1104.95	20.05	0.40	1086.90
Softwood pellets, particle size 0.300 to 0.425mm												
0	139.26	8	60	16.24	0.06	20.09	8.09	23.71	1144.06	20.24	0.74	1116.36
15	139.26	8	60	16.09	0.08	19.87	8.08	23.49	1157.53	20.13	1.29	1123.30
30	139.26	8	60	16.03	0.04	19.76	8.09	23.27	1156.67	19.98	1.10	1125.92
(Note: intermediate data was intentionally cut to save space)												
0	159.16	10	70	15.31	0.07	20.03	8.10	30.83	1130.80	20.19	0.79	1101.27
15	159.16	10	70	15.18	0.05	19.91	8.09	31.16	1139.35	20.04	0.65	1110.71
30	159.16	10	70	14.94	0.06	19.75	8.08	32.20	1149.06	19.85	0.50	1128.63
Softwood pellets, particle size 0.150 to 0.300mm												
0	139.26	8	60	15.77	0.08	20.02	8.09	26.95	1135.72	20.18	0.79	1117.36
15	139.26	8	60	15.68	0.06	19.83	8.09	26.47	1142.28	19.97	0.70	1126.38
30	139.26	8	60	15.57	0.03	19.69	8.08	26.46	1151.97	19.82	0.66	1136.93
(Note: intermediate data was intentionally cut to save space)												
0	159.16	10	70	14.52	0.04	19.49	8.08	34.23	1159.49	20.18	3.42	1108.05
15	159.16	10	70	14.41	0.07	19.35	8.09	34.28	1161.27	19.83	2.42	1125.31
30	159.16	10	70	14.37	0.03	19.63	8.08	36.60	1145.45	19.75	0.61	1130.40