# Mechanical characteristics of standard fuel briquettes on biomass basis

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**ABSTRACT**: The measuring has proved that the energy herbs can be pressed into the form of compact briquettes. It regards 9 varieties of the energy crops, i.e. coriander, crambe, saphlor, sorrel, sorghum, reed canary grass, knotweed, barley straw and rapeseed straw. These energy crops are disintegrated by the grinding mill ŠV 15 (manufacturer Stoza, Ltd.) before the pressing. The fraction size is given by the mesh size of circular cross section of diameter 15 mm. All the crops have constant moisture content during the measuring and uniform diameter 65 mm of the resulting briquettes. The biomass moisture ranges from 9 to 11%. The pressing is conducted by the briquette press HLS 50 (manufacturer Briklis, Ltd.). The measuring results have shown the highest volume weight in following energy herbs: coriander, saphlor, rapeseed straw, sorghum, sorrel and knotweed. The lowest volume weight was found in these crops: reed canary grass, crambe and barley straw. The measuring proved that the highest force for the briquette disintegration is necessary for knotweed, saphlor, sorrel, sorghum and coriander. The lowest force for the briquette disintegration needs the reed canary grass, barley and rapeseed straw and crambe. Crambe contains a high level of oil in its seeds and this fact causes difficulties during their pressing as good mechanical parameters regards, thus they cannot be pressed into the briquette form.

**Keywords**: briquetting; energy herbs; briquette mechanical properties; briquette volume weight; force for briquettes disintegration

At present the biomass is the only energy resource that could be in near future utilized for the objectives the Czech Republic previews for year 2010. It means to reach a 6% share of energy renewable sources from total energy consumption and at the same time 8% of electric energy production from those sources. From the purposefully grown biomass can be used the energy herbs and wood species. An advantage of the energy herbs compared with the wood species is lower costs for growing and consequent processing. The energy herbs biomass can be directly used for combustion in form of chopped material or pressed into the bales or it can be further processed into briquettes or pellets. Through the briquettes production there is achieved the standard form of that fuel for its further utilization in the combustion device. This processing enables to achieve a significant volume contraction and thus also matter and utilized energy density increasing (Plíštil 2003; Plíštil, Nováková 2003; Juchelková, Plíštil 2004; Juchelková et al. 2004).

As the mechanical properties of the standardized fuels in form of briquettes concerns, the most important are the volume weight and mechanical strength. These parameters depend on the used material, its structure, water content and compaction pressure. The basic standard for this process is the Austrian ÖNORM M 7135 and German DIN 51731. These documents are valid for wood and bark extrusions. For the material volume weight is determined the value $\rho > 1{,}000\ kg/m^3$. If the briquettes are of circular section type then their diameter is from 20 to 120 mm and length till 400 mm. The legal regulation in the Czech Republic for the wood briquettes requirements is the Decree 357/2000 specifying demands for fuel quality from the point of view of atmosphere protection. Nevertheless this decree does not present requirements for the fuel mechanical properties. The briquette mechanical

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strength is characterized by the force necessary for its destruction (Brožek 2001). The briquette of circular cross section is exposed to the pressure force as shown in Fig. 1, i.e. its direction is perpendicular to its axis of symmetry. The values of these destructive forces are known for various materials (Plíštil, Herák 2004; Brožek 2001).

The briquetting is the most applied technology of fuel compaction. The result is a briquette of cylindrical or square shape. With briquetting it is possible to reach a considerable reduction of the material volume. This method can be used to process different inflammable materials as for example: wood sawdust, shavings, wood dust, bark, chips, cardboard, waste paper, paper cuttings, assorted municipal waste combustible fraction, flax chaff, technical hemp, jute waste, waste from pencils production, cellulose and waste from pulp and paper mills, hay, straw, cuttings and dust from leather production, maize stems, rapeseed straw, nut shells, coal and coke dust etc.

It is advisable to add coal dust is small amount into the biomass due to better briquettes cohesion and consequently better mechanical properties (Plíštil, Herák 2004). The wood sawdust is probably a suitable material for briquetting (Cheremisinoff 1980). For heating briquettes is valid the directive No. 14–98 of the Ministry of the Environment are determining the wood waste properties for a valuable fuel without additional binder. The culm crops and other crop waste introduction into the system of the energy carrier distribution is complicated due to the necessity of handling a huge biomass amount per energy unit. The biomass compaction by pressing seems to be a key for the handling, transport, storage facilitation as well as the heat conversion performed by

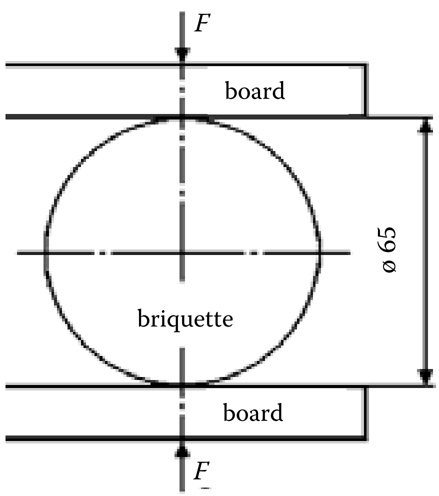


Fig. 1. Course of briquette pressure – mechanical test

combustion, gasification or pyrolysis. In addition, the biomass compaction represents a certain way of the solid biofuels introduction with the uniform properties, specified by the technical requirements. The technical and logistics advantages of the extrusion products are evident. This currently regards in particular briquettes and pellets.

According to the standard ČSN 44 1309 the mechanical test for abrasion is performed. The abrasion briquette strength is the share of the briquettes tested sample graining above 25 mm expressed in the weight percentage of the original briquette batch.

From the currently grown energy crops, the highest production potential and therefore also a perspective have knotweed and energy sorrel. These energy herbs have a high yield of phytomass and belong among perennial herbs with the vegetation period more than 10 years at the same growing site. Their mechanical parameters are the best from all energy herbs subsidized in the Czech Republic. Their advantage is a wooden part of the stalk having the same mechanical parameters as hard wood during the briquette pressing (Juchelková, Plíštil 2004).

The better briquette strength achievement is based on the presumption that a higher material amount in the pressing chamber causes better briquette compaction, the briquette is longer and more intensive force is necessary for its entire decomposition (Plíštil 2003).

## METHODS

The materials utilized for the briquette production are the herbs purposefully grown for the energy use. From the energy crops the sorrel was used (*Rumex thianshanicus* × *Rumex patientia*), reed canary grass (*Phalaroides arundinacea*), knotweed (*Reynoutria sachalinensis*), sorghum (*Sorghum vulgare*), coriander (*Coriandrum sativum*), crambe (*Crambe abyssinica*), saphlor (*Carthamus tinctorius*). Besides these crops also the barley and rapeseed straw briquettes were pressed into the form of briquettes.

During the briquetting the biomass is transported into the hopper situated over the press. One wall of the hopper is vibrating to prevent the vault formation and perfect filling of the pre-press trough. In the first phase the biomass is pre-compacted and pushed into the pressing space by means of two hydraulic cylinders. The pressed biomass is gradually after-pressed in the pressing chamber in two phases – by the rapid traverse and full force of the main cylinder in the final briquette form. From the opposite side the press-mould is closed by the support hydraulic cylinder. After its relief the briquette falls out from the press-mould. The supporting cylinder construction allows the two-way pressing.

The pressing tools are mounted in the compact block for rapid and easy exchange after their wear. The pre-press hydraulic cylinders are used for the block shifting out.

The energy crops were first disintegrated in the hammer grinding mill ŠV 15 (manufacturer Stoza, joint-stock company). The grinding mill input is 15 kW, the grinding output is 2.2–3.2 t/h depending on the used material.

The energy crops have constant moisture content during the experiments. The input moisture ranges from 9 to 11%.

From the materials treated as described above briquettes were pressed by the briquetting press HLS 50 (manufacturer Briklis, joint-stock company).

The volume weight (density) of the produced briquettes was found by a simple method as a ratio of weight and volume determined from the briquette geometric shape. By that procedure were measured several pieces of briquettes of each material, produced at various pressure.

The briquette mechanical strength was investigated by the method of transverse splitting. For this test was used the tensile machine ZDM 5 t.

The briquette is exposed to the action of the force (Brožek 2001, see Fig. 1), which is perpendicular to the briquette axis of symmetry. This force is gradually increased until the briquette disintegration and splitting.

The destruction force intensity was investigated for several samples of each material, generated at various pressures. The experiment was carried out according to the regulation on the withdrawal, adaptation and test methodology. The pressure is developed through a tapered conical matrix. This matrix is acting as a resistance against the pressing.

**Samples withdrawal and preliminary adaptation**

The samples breaking up scheme is shown in Fig. 2. It concerns the briquette number that must be withdrawn for the test according to the appropriate standards. The purpose is to determine the bio-briquette volume weight.

The energy biomass breaking up according to the Ministy of the Environment No. 381/2001 is divided into the agricultural and forestry products.

It regards:

– non-contaminated crop waste from the primary agricultural and horticultural production and forestry,
– wooden waste is the non-contaminated form of wooden material, wood treatment waste (saw mill wood processing, board and furniture production),

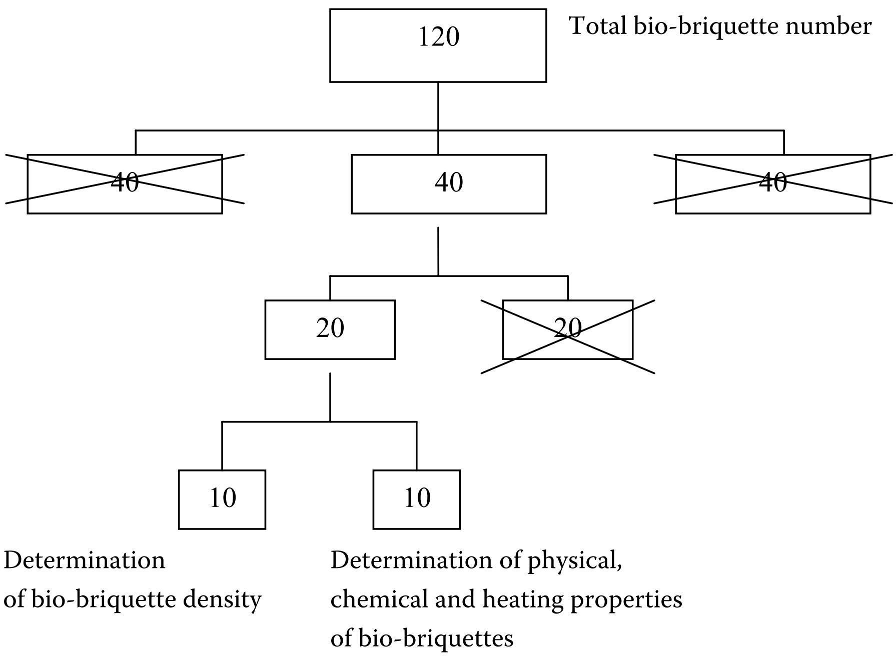


Fig 2. Briquette sample breaking up scheme for their properties determination

– 191206 municipal waste and similar from offices, industry, business – wood.

## RESULTS AND DISCUSSION

The graphical values are ranging for individual materials only within the illustrated areas. These areas depend on the pressed material type and its absolute moisture. The graphical dependencies found are shown in the following graphs. It concerns the following dependencies and their graphical illustration: Graphical illustration of the briquette density dependence on the pressing pressure is presented in Fig. 3. Graphical illustration of the destructive force dependence on the pressing pressure is presented in Fig. 4. Mathematical expression of the briquette density dependence on the pressing pressure is illustrated in Table 1. Mathematical expression of the destructive force dependence on the pressing force dependence on the pressing pressure is presented in Table 2. In the both cases the dependencies were substituted by the linear course. The force intensity is illustrated for each material in dependence on the pressing pressure. The destructive force is expressed in the unit of N per 1 mm of the length.

From Fig. 3 resulted the dependence of the briquette density (ρ) changes on the pressing pressure $p_D$. From Fig. 4 resulted dependence of the force $F$ changes, what is the necessary pressing pressure $p_D$.

The results of measuring have indicated that the materials are pressed under the different pressure. It is caused by the material amount transported into do compacting matrix. If the matrix capacity is large and thus also the material amount is larger, then the pressing machine produces a higher pres-

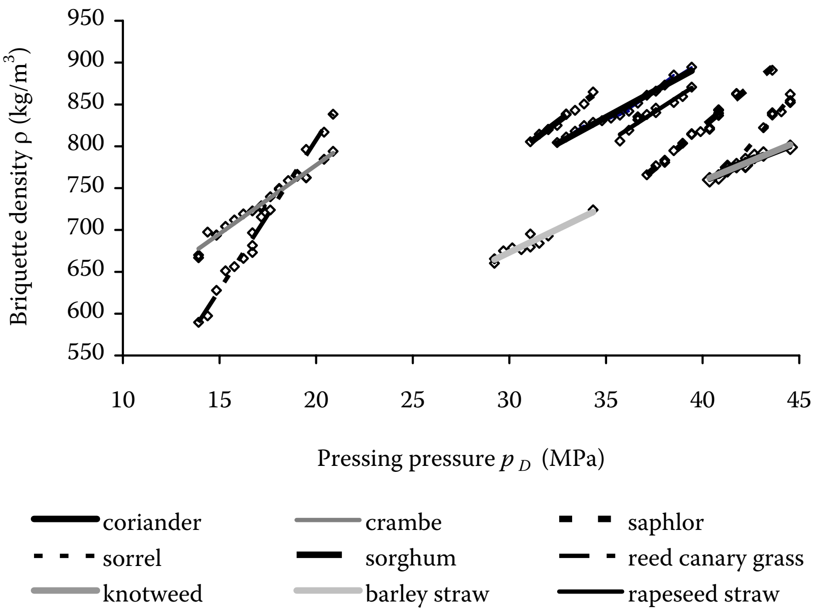


Fig. 3. Briquette density dependence on the pressing pressure

Table 1. Mathematical expression of briquette density dependence on the pressing pressure

| Material of briquettes | Equation of regression | Determination coefficient |
|---|---|---|
| Coriander | $\rho = 12.513p_D + 396.73$ | $R^2 = 0.9762$ |
| Crambe | $\rho = 16.419p_D + 449.18$ | $R^2 = 0.9778$ |
| Saphlor | $\rho = 19.8p_D + 30.813$ | $R^2 = 0.9837$ |
| Sorrel | $\rho = 27.484p_D – 366.14$ | $R^2 = 0.9276$ |
| Sorghum | $\rho = 17.514p_D + 260.02$ | $R^2 = 0.9838$ |
| Reed canary grass | $\rho = 35.825p_D + 91.042$ | $R^2 = 0.9885$ |
| Knotweed | $\rho = 9.5167p_D + 378.03$ | $R^2 = 0.9465$ |
| Barley straw | $\rho = 11.143p_D + 338.88$ | $R^2 = 0.9097$ |
| Rapeseed straw | $\rho = 14.971p_D + 279.4$ | $R^2 = 0.9424$ |

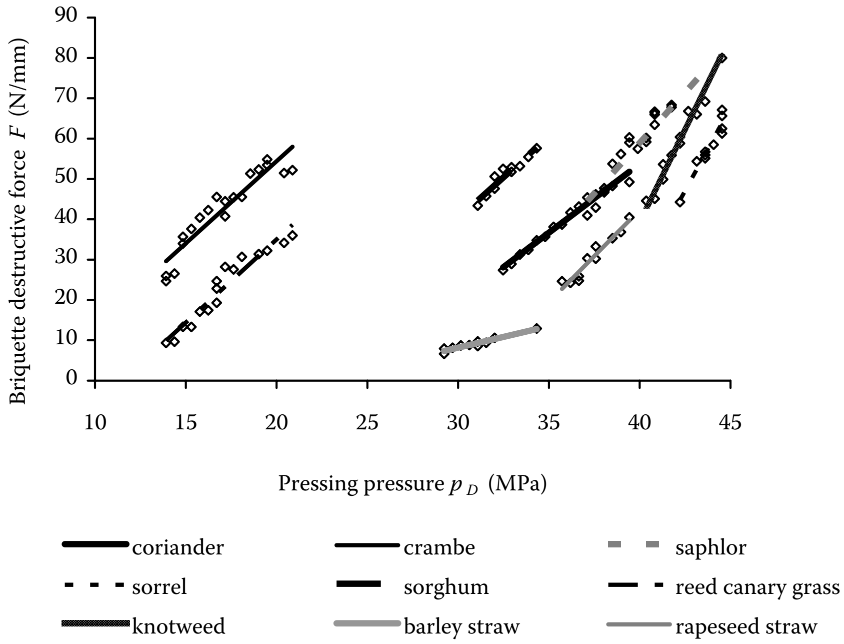


Fig. 4. Briquettes destructive force dependence on the pressing pressure

Table 2. Mathematical expression of briquette destructive force on pressing pressure

| Material of briquettes | Equation of regression | Determination coefficient |
|---|---|---|
| Coriander | $F = 3.4087p_D - 82.612$ | $R^2 = 0.9822$ |
| Crambe | $F = 4.0758p_D - 27.123$ | $R^2 = 0.8799$ |
| Saphlor | $F = 4.9997p_D - 141.06$ | $R^2 = 0.8726$ |
| Sorrel | $F = 8.2415p_D - 303.15$ | $R^2 = 0.9219$ |
| Sorghum | $F = 4.061p_D - 81.557$ | $R^2 = 0.9161$ |
| Reed canary grass | $F = 4.1277p_D - 47.539$ | $R^2 = 0.9257$ |
| Knotweed | $F = 8.8004p_D - 311.77$ | $R^2 = 0.9741$ |
| Barley straw | $F = 1.0641p_D - 23.727$ | $R^2 = 0.9184$ |
| Rapeseed straw | $F = 4.5774p_D - 140.77$ | $R^2 = 0.94$ |

sure, the final briquettes are longer and therefore their strength is also higher.

Crambe and reed canary grass are compacted by the pressure ranging from 14 to 20 MPa. For the reed canary grass is necessary the higher portioning into the matrix to reach the higher pressure. Afterward the reed canary grass has reached the volume weight up to 804 kg/m$^3$, what is relative high value as this energy crop concerns. Crambe is influenced by the seeds disintegrated together with this crop. Because the seeds contain oil, the material cannot be pressed into the compacted form. The pressing was characterized by the sound (roar) caused by the oil pressing from the briquette and its consequent flowing out from the pressing machine.

The other herbs are pressed in the approximately similar interval of the pressing pressure. Only the barley straw has lower volume weight compared with the other energy crops. The best volume weight has coriander, sorghum and saphlor.

In comparison with the standards ÖNORM M 7135 and DIN 51 731 it is evident that the values of the volume weight do not reach 1,000 kg/m$^3$ in the used briquetting equipment HLS 50, which is a value required for the wood and bark extrusions.

The following materials are characterized by the low volume weight and force necessary for the briquette destruction: barley straw and reed canary grass.

The most intensive force for the briquette destruction needs saphlor, sorrel, knotweed and sorghum.

The lower quality of briquettes was proved for barley straw, reed canary grass and rapeseed straw.

**The measured biomass values:**

1. coriander:
   a) volume weight 800–900 kg/m$^3$
   b) destruction force 30–50 N/mm
   c) range of pressing pressure 32–40 MPa
2. crambe:
   a) volume weight 670–800 kg/m$^3$
   b) destruction force 25–55 N/mm
   c) range of pressing pressure 14–21 MPa
3. saphlor:
   a) volume weight 760–890 kg/m$^3$
   b) destruction force 40–70 N/mm
   c) range of pressing pressure 37–43 MPa
4. sorrel:
   a) volume weight 800–860 kg/m$^3$
   b) destruction force 45–70 N/mm
   c) range of pressing pressure 42–45 MPa
5. sorghum:
   a) volume weight 800–870 kg/m$^3$
   b) destruction force 40–60 N/mm
   c) range of pressing pressure 31–35 MPa
6. reed canary grass:
   a) volume weight 600–840 kg/m$^3$
   b) destruction force 10–35 N/mm
   c) range of pressing pressure 14–21 MPa
7. knotweed:
   a) volume weight 760–800 kg/m$^3$
   b) destruction force 45–80 N/mm
   c) range of pressing pressure 40–45 MPa
8. barley straw:
   a) volume weight 650–730 kg/m$^3$
   b) destruction force 6–13 N/mm
   c) range of pressing pressure 29–34 MPa
9. rapeseed straw:
   a) volume weight 800–860 kg/m$^3$
   b) destruction force 24–40 N/mm
   c) range of pressing pressure 35–40 MPa

The pressing pressures are given by the biomass structure and influenced by the material resistance developed in the tapered matrix of the pressing machine. From the mechanical test resulted that the briquette is stabilized and then destructed. But this is only one method of the mechanical parameters measuring having an advantage in the mathematical record achievement, which can be compared with the laboratory samples (Brožek 2001).

The measured values of the real briquetting press HLS 50 are compared with a measuring carried out with a model of the briquetting press of the Department of Material and Engineering Technology, conducted by the authors Brožek (2001), Bartoš (2000) and Toniniová (2002).

By utilization of the press HLS 50 was reached the higher stage of compaction at the comparable pressing pressure than under the laboratory conditions. The pressed phytomass in the real pressing machine has better mechanical parameters than the pressed phytomass under the laboratory conditions. In the laboratory only is investigated mutual dependence of the mechanical parameters regardless of the difficulty and effectiveness of that research.

## CONCLUSION

The pressing performed by the briquetting press HLS 50 resulted in the higher compaction and this needs a more intensive force for the briquette destruction. The straw briquettes cannot be compacted by the briquetting press HLS 50 in the quality represented by the samples of knotweed, sorrel and saphlor.

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## Mechanické vlastnosti energetických briket vyrobených z biomasy

**ABSTRAKT**: Měřením se zjistilo, které energetické byliny je možné lisovat do kompaktních briket. Je to devět druhů energetických rostlin: koriandr, krambe, saflor, šťovík, čirok, chrastice, křídlatka, ječmenná sláma a řepková sláma. Tyto energetické rostliny jsou před lisováním dezintegrovány na šrotovníku ŠV 15 (výrobce Stoza, s. r. o.). Velikost frakce je udána velikostí ok síta, kruhového průřezu o průměru 15 mm. Všechny rostliny mají během měření neměnnou vlhkost a jednotný průměr výstupních briket o průměru 65 mm. Vlhkosti biomas se pohybují v rozmezí 9–11 %. Lisování se provádí v briketovacím lisu HLS 50 (výrobce Briklis, s. r. o.). Z výsledků měření vyplývá, že nejvyšší hmotnost mají tyto energetické byliny: koriandr, saflor, řepková sláma, čirok, šťovík a křídlatka. Nejnižší objemovou hmotnost mají chrastice, krambe a ječmenná sláma. Z výsledků měření vyplývá, že největší sílu na porušení brikety, která je porušována mezi dvěma deskami, je zapotřebí u křídlatky, safloru, šťovíku, čiroku a koriandru. Nejmenší sílu na porušení celistvosti brikety je zapotřebí vynaložit u chrastice, ječmenné a řepkové slámy a krambe. Krambe obsahuje v semínkách hodně oleje; při lisování nezaručí dobré mechanické parametry, takže semínka nejdou lisovat do tvaru brikety.

**Klíčová slova**: briketování; energetické byliny; mechanické vlastnosti briket; objemová hmotnost briket; síla na porušení briket

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