MEAN ATOMIC WEIGHT OF STUBENBERG METEORITE. M. Szurgot, Lodz University of Technology, Center of Mathematics and Physics, Al. Politechniki 11, 90 924 Lodz, Poland, (mszurgot@p.lodz.pl).

Introduction: Stubenberg meteorite is a very intersting LL6 chondrite, which fell on March 6th, 2016 in Germany [1]. Mineralogical, chemical, and some physical characteristics of this new meteorite have been recently reported [1]. It was established that Stubenberg is a fragmental breccia, weekly shocked (S3) **[**1]. The aim of the paper was to determine and analyze mean atomic weight and mean atomic number of the Stubenberg meteorite, and to predict grain density of the chondrite. Mean atomic weight and mean atomic number, bulk and grain densities are important properties to characterize minerals, rocks, planets, moons and asteroids, and are important to classify meteorites, and to characterize meteorite parent bodies [2-11]. The bulk composition of Stubenberg, and mineral composition determined by Bischoff and co-workers [1] was applied in calculations.

Results and discussion: Bulk composition of the meteorite has been used to calculate mean atomic weight *Amean* and mean atomic number *Zmean* using the following formulas:

$$Amean = \sum wi/\sum(wi/Ai), \quad (1)$$

$$Zmean = \sum wi/\sum(wi/Zi), \quad (2)$$

where *wi*(wt%) is the mass fraction of i*th* element, and *ith* oxide, *Ai* is atomic weight of i*th* element, and *Zi* is atomic number of i*th* element. Apart from elements and oxides, which concentration (*wi*) was determined by Bischoff and co-workers [1] by inductively coupled plasma atomic emission spectroscopy (ICP-AES), and inductively coupled plasma sector field mass spectrometry (ICP-SFMS), concentration of certain elements such as: Si, S, C, and O was added in calculations, assuming that Stubenberg meteorite contains the mean abundance of Si (19.01 wt%), S (2.05 wt%), C (0.07 wt%), and O (37.38 wt%) as the other LL6 chondrites falls, according to Jarosewich's data [12].

Apart from the bulk composition data, also *Fe/Si* ratio, grain density *dgrain*, and magnetic susceptibility *χ* were used to predict *Amean* values by *Amean(Fe/Si)*, *Amean(dgrain)*, and *Amean(logχ)* relationships, recently established by Szurgot (e.g. [2-6, 9-10]):

$$Amean(Fe/Si) = 5.72\cdot Fe/Si + 20.25, \quad (3)$$

$$Amean(dgrain) = 7.51\cdot dgrain - 2.74, \quad (4)$$

$$Amean(\log\chi) = 1.49\cdot \log\chi + 16.6. \quad (5)$$

$$Amean(Fe/Si,d,\chi) = [Amean(Fe/Si)+Amean(dgrain)+ Amean(\log\chi)]/3. \quad (6)$$

Table 1 compiles values of *Amean*, *Zmean* and *Amean/Zmean* ratios calculated for bulk composition of Stubenberg, Ensisheim, Chelyabinsk, Olivenza, Siena, Hautes Fagnes, NWA 7915, Sołtmany, and Braunschweig chondrites. Data concern falls and one find (NWA 7915), and the bulk composition of meteorites does not include H_2O.

Table 1 Mean atomic weight *Amean*, mean atomic number *Zmean*, *Amean/Zmean* ratio, and *Fe/Si* atomic ratio of Stubenberg, Ensisheim [6], Chelyabinsk [9], Olivenza, Siena [10], Hautes Fagnes [10], NWA 7915 [10], Sołtmany [2], and Braunschweig [7] chondrites.

Meteorite (class)	*A*	*Z*	*A/Z*	*Fe/Si*
Stubenberg (LL6 S3)	**23.65**	**11.70**	**2.021**	**0.551**
Ensisheim (LL6 S4)	23.32	11.51	2.026	0.509
Chelyabinsk				
Light lith.	23.47	11.58	2.027	0.545
Dark lith.	**23.63**	**11.66**	2.027	**0.571**
Mean* (LL5 S4)	23.52	11.61	2.026	**0.553**
Olivenza (LL5 S3)	23.29	11.50	2.025	0.493
Siena (LL5)	24.47	12.10	2.022	0.734
Hautes Fagnes (LL5 S1)	23.11 23.35	11.44 11.56	2.020	0.529
NWA 7915 (LL5 S2)	22.80	11.29	2.019	0.529
Sołtmany (L6 S2)	23.97	11.85	2.022	0.588
Braunschweig **(**L6 S4)	**23.68**	**11.72**	**2.021**	0.587

*2/3 light lithology + 1/3 dark lithology.

Table 2 *Amean* values of Stubenberg, determined by bulk composition (eq.(1)), minerals composition (eq.(1)), and by relationships (eqs *(3) - (6))*.

Bulk	*Minerals*	*Fe/Si*	*dgrain*	*χ*	*Fe/Si,d,χ*
23.65	23.33	23.40*	23.70**	22.09#	23.06

***For Stubenberg *Fe/Si* = 0.551, ****for *dgrain* = 3.52 g/cm^3 predicted by eq. (8). #For *logχ* = 3.683 ± 0.015 [1].

Tables 1 and 2 show that Stubenberg *Amean(Bulk composition)* = 23.65 is close to the mean atomic weight of Braunschweig (23.68)**,** and to Chelyabinsk *Amean* (23.47 for light lithology, and 23.63 for dark lithology), and Stubenberg *Fe/Si* atomic ratio (0.55) is close to Chelyabinsk *Fe/Si* atomic ratio (0.55).

In addition, Stubenberg *Amean/Zmean* ratio (2.021) and Braunschweig *Amean/Zmean* ratio (2.021) are identical, and Stubenberg *Zmean* (11.7), Braunschweig *Zmean* (11.7), and Chelyabinsk *Zmean* (11.6) are very close to each other.

Table 2 reveals that *Fe/Si* atomic ratio and grain density satisfactorily predict *Amean* values for Stubenberg, and magnetic susceptibility leads to too low value of *Amean*. Arithmetic mean $Amean(Fe/Si,d,\chi)$ = 23.06 ± 0.86 confirms that Stubenberg is one of LL chondrites (*AmeanLL* = 22.90 [4]), but *Amean* value determined by bulk composition (23.65) indicates rather L/LL intermediate group (*AmeanL/LL* = 23.34 ± 0.19 [4]), or even L group (*AmeanL* = 23.67 [4]), and *Fe/Si* ratio (0.55) indicates L/LL group (*Fe/SiL/LL* = 0.54 ± 0.03 [4]).

Second column in Table 2 presents the Stubenberg mean atomic weight *Amean(Minerals)* calculated by minerals composition (eq. (1)), and *wi*(wt%) is here the mass fraction of i*th* mineral, and *Ai* is atomic weight of i*th* mineral. Using the same modal compostion for Stubenberg as that for Ensisheim chondrite [13], and mean atomic weights of main minerals of the Stubenberg: olivine Fa31.4Fo68.6 [1] (*wOL* = 0.5332, *AOL*=22.928), low Ca pyroxene En72.6Fs25.4Wo2 [1] (*wOpx* = 0.1947, *AOpx* = 21.743), high Ca pyroxene En47.4Fs11.2Wo41.4 [1] (*wCpx* = 0.0632, *ACpx* = 22.091), plagioclase Ab83.4An11.1Or5.5 [1] (*wPL* = 0.1027, *APL* = 20.397), troilite ((*wtr* = 0.0599, *Atr =43.954*), Fe,Ni metal (kamacite Fe90Ni3.9Co6.1 [1], and taenite Fe53.68Ni44.39Co1.8Cu0.22 [1]) (*wMe* = 0.024, *AMe =56.636*) leads to *Amean(Minerals)*= 23.33. *Amean's* values of Stubenberg minerals: *AOL*, *AOpx*, *ACpx*, *WPL*, *Atr*, and *AMe* were calculated by eq. (1), using the mineral composition established by Bischoff and co-workers [1].

Bulk density of the Stubenberg chondrite was measured by Bischoff et al. (*dbulk* = 3.40 g/cm^3) [1]. Grain density has not been determined so far. To predict grain density *dgrain* of the Stubenberg chondrite relationships discovered by Szurgot [2, 3, 9-11] have been used.

First relationship is between density *dgrain* and *Fe/Si* atomic ratio. It is given by the equation [11]:

$$dgrain(Fe/Si) = 0.765 \cdot Fe/Si + 3.11. \qquad (7)$$

Substituting *Fe/Si* = 0.551 into eq. (7) gives *d* = 3.53 ± 0.07 g/cm^3 for grain density of Stubenberg meteorite.

Apart from the *Fe/Si* ratio, also mean atomic weight *Amean* enables one to predict grain density for ordinary chondrites. The relationship between grain density and mean atomic weight *dgrain(Amean)* is expressed by the equation [2, 3]:

$$dgrain(Amean) = 0.133 \cdot Amean + 0.37. \qquad (8)$$

Substituting *Amean* = 23.65 into eq. (8) gives *dgrain* = 3.52 ± 0.07 g/cm^3 for grain density of Stubenberg meteorite.

Third prediction of *dgrain* is based on the modal composition of the meteorite, and grain densities of constituent minerals. It is given by the equation:

$$dgrain(minerals) = \sum wi / \sum (wi/di), \qquad (9)$$

where *wi*(wt%) is the mass fraction of i*th* mineral, and *di* is grain density of i*th* mineral.

Using the same values of *wi*(wt%) for Stubenberg minerals, as previously for *Amean(minerals)* determination, and grain densities: 3.58 g/cm^3 for olivine, 3.2 g/cm^3 for both pyroxenes, 2.7 g/cm^3 for plagioclase, 4.74 g/cm^3 for troilite, and 7.9 g/cm^3 for Fe, Ni metal (kamacite and taenite) leads to grain density of Stubenberg *dgrain(minerals)* = 3.49 g/cm^3 (Table 3).

Table 3 Grain density *d(g/cm³)* of Stubenberg meteorite, determined by relationships expressed by eqs. (7) - (9).

d(Fe/Si)	*d(A)*	*dminerals*	*dmean*
3.53	3.52	3.49	**3.51**

Grain density values predicted for Stubenberg meteorite: 3.49, 3.52, 3.53, and mean density: 3.51 ± 0.02 g/cm^3 are reasonable since they are close to the mean value for grain density of LL falls (3.52 g/cm^3 [14]).

Conclusions: Mean atomic weight of Stubenberg LL6 chondrite is close to the mean atomic weight of Chelyabinsk LL5 chondrite, and is close to *Amean* of Braunschweig L6 chondrite. Stubenberg *Fe/Si* ratio is close to the Chelyabinsk *Fe/Si* ratio. Predicted grain density for Stubenberg meteorite is close to the mean grain density of LL falls.

References: **[**1] Bischoff A. et al. (2017) *Metoritics & Planet. Sci.*, *52*, 1683-1703. [2] Szurgot M. (2015) *Acta Societ. Metheor. Polon.*, *6*, 107-128. [3] Szurgot M. (2015) *LPSC XLVI*, Abstract #1536. [4] Szurgot M. (2016) *LPSC XLVII*, Abstract #2180. [5] Szurgot M. (2017) *LPS XLVIII*, Abstract #1130. [6] Szurgot M. (2017) *Acta Societ. Metheor. Polon. 8*, 110-122. [7] Szurgot M., Wach R. A., Bartoschewitz R. (2017) *Metoritics & Planet. Sci., 52 Suppl. S1*, #6002.pdf. [8] Szurgot M. (2016) *Metoritics & Planet. Sci., 51 Suppl. S1*, #6021.pdf. [9] Szurgot M. (2015) *Metoritics & Planet. Sci. 50 Suppl. S1*, #5008.pdf. [10] Szurgot M. (2016) *Acta Societ. Metheor. Polon., 7*, 133-143. [11] Szurgot M. (2017) *Metoritics & Planet. Sci., 52 Suppl. S1*, #6008.pdf. [12] Jarosewich E. (1990) *Meteoritics, 35,* 323-337. [13] McSween H. Y. et al. (1991) *Icarus, 90,* 107-116. [14] Macke R. J. (2010) *PhD Thesis*, Univ. Central Florida, Orlando.