Physical properties of the returned sample of Ryugu by Hayabusa2 mission

S.Tanaka[1], H.Nagano[2], T.Yagi,[3] Y.Ino[1,4], T.Tsuji[5], M.Sato[6], K.Kurosawa[7], Y.Nagaashi[8], D.Nakashima[9], T.Ishizaki[1], T.Kawahara[2], N.Sakatani[10], R.Endo[11], M.Susa[11], Y.Yamashita[3], T.Nishi[12], H.Ohta[12], Y.Suganuma[12], S.Tachikawa[1], T.Kawamura[13], T.Kobayashi[14], K.Onodera[1], G.Nishiyama[6], T.Michikami[17], K.Hattori[3], Y.Tanaka[3], M.Yoshioka[3], A.Tsuchiyama[14,15], Y.Kimura[16], T.Hatakeyama[18], S.Sugita[6], R.Fujita[2], A.Abdulkareem[2], T.Nakamura[9], T.Morita[9], M.Kikuri[9], K.Amano[9], E.Kagawa[9], H.Yurimoto[16], T.Noguchi[19], R.Okazaki[5], H.Yabuta[20], H.Naraoka[5], K.Sakamoto[1], S.Tachibana[6], S.Watanbe[2], Y.Tsuda[1]

[1]Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency(ISAS/JAXA) (Kanagawa 252-5210, Japan, tanaka@planeta.sci.isas.jaxa.jp), [2]Nagoya Univ.(Nagoya 464-8601, Japan),[3] National Institute of Advanced Industrial Science and Technology(AIST)(Tsukuba 305-8565, Japan), [4]Kwansei Gakuin University (Sanda 669-1337, Japan), [5]Kyushu Univ.(Fukuoka 812-8581, Japan), [6]Univ. Tokyo (Tokyo 113-0033, Japan), [7]Planetary Exploration Research Center, Chiba Institute of Technology(PERC)(Narashino 275-0016, Japan.), [8]Kobe Univ.(Kobe 657-8501, Japan), [9]Tohoku Univ.(Sendai 980-8578, Japan), [10]Rikkyo Univ. (Tokyo 171-8510, Japan), [11]Tokyo Institute of Technology (Tokyo 152-8550, Japan), [12]Ibaraki Univ.(Hitachi 316-8511, Japan), [13]Institut de Physique du Globe de Paris/Université de Paris(Paris 75205, France), [14]Ritsumeikan University (Kyoto 603-8577, Japan), [15]CAS, Guangzhou Institute of Geochemistry (Guangzhou 510640, China), [16]Hokkaido University (Sapporo 060-0819, Japan), [17]Kindai University (Hiroshima 739-2116, Japan), [18]Okayama Univ. of Science (Okayama 700-0005, Japan), [19]Kyoto Univ.(Kyoto 606-8502, Japan), [20]Hiroshima Univ. (Higashi-Hiroshima 7390-8526, Japan)

Introduction: The sample of the C-type asteroid 162173 Ryugu was successfully collected from surface by the two times of touchdown operations of Hayabusa2 mission and returned to Earth on 6th Dec. 2020. The total amount of the sample was unexpectedly large as 5.4g in total mass, and some samples had about 100 mg in mass and about 10mm in majour axis length[1].

The physical properties which involve four categories as mechanical, thermal, electrical, and magnetic, could give basic parameters of collisional, thermal and others related to the origin and evolution of the body, and they also give us essential clues to understanding of results from remotesensing observations.

In order to meaure the physical properties of the sample effectively and efficiently, Ryugu samle Physical Property Measurement Team (Ryugu-PPMT) was organized about two years before sample return to Earth. This team was positioned as part of 'rock team' which mainly treated larger samples[2]. We prepared and developed measurement methods and conducted reheasal measurements using small amount (size) and breakable analogue samples. In this paper, we report a summary of the physical properties measured as an activity of initial sample analysis.

Sample and sample processing : The sample we measured intensively was one of the largest samples collected at the second touch down operation[2]. It's size of major and minor axes is around 9×5×3 mm. Table 1 summarize a list of physical properties prepared for the initial analysis and also indicate the minimum and nominal requirement of sample size (or sample mass) for each measurement. Many of them require two flat end surface and the size of ϕ3×1mm disk-like shape, therefore, we requested to cut the sample along the minor axis. Since a large number of small cracks were found by X-ray CT observaion, the sample was thought to be easily breakable. In order to avoid destruction by the cutting process, the whole sample was molded by glycol phthalate (hereafter:GF) in the glass tube at around 100℃. GF was too viscous at this temperature to permeate the texture in the sample. Then, the sample was cut in parallel by a diamond-wire-saw with the thickness of 0.5-1.0mm[3]. After cutting, the sample was re-heated to remove the GF, and polished bothsides by SiC lapping film under dry condition.

As the result, two sliced disk-like shape pieces both of which had about 9-10mm^2 and the thickness of 0.75 and 0.9mm were processed for the physical properties measurement.

Physical properties measurement: The measurements were conducted at different universities,and institute as shon in Table1 in order of least likely to damage to the sample. For example, thermal diffusivity measurement which was firstly applied was non-contact, on the other hand, elastic velocity measurement which was done last required the sample sandwiched by the transducers with a proper loading. Finally, the samples were process to rectangular shape, and were fractured by bending test to measure the strength of the sample[4]. After that, they are pulvetized into small particles to measure cohesive force. For the magnetic measurement, a small fragment of about 0.3mm size, which was unexpectedely separated from the large sample by the removing process from GF, was used.

Category	physical property	method	minimum. size,mass	nominal size, mass	flattness	meas. Inst/Univ.
Mechanical Properties	Hardness	Nanoindentation test	ϕ0.1×0.1(Rd)	ϕ1×0.5(Rd)	one-side	ISAS, AIST
	Young's modulus	Nanoindentation test	ϕ0.1×0.1(Rd)	ϕ1×0.5(Rd)	one-side	ISAS, AIST
	Bending strength	three point bending test	1.5×1×0.5(Rec)	80×10×4(Rec)	two-sides	ISAS, PERC
	longitudinal velocity	elastic wave transmission method	ϕ1×0.5(Rd)	ϕ3×1(Rd)	two-sides	ISAS
	shear velocity	elastic wave transmission method	ϕ1×0.5(Rd)	ϕ3×1(Rd)	two-sides	ISAS
	thermal expansivity	mechanical dilatometers	1×1×1(Rec)	3×1×1(Rec)	N/A	ISAS
	cohesion force	centrifugal-method	ϕ0.02(Sd)	ϕ0.02－0.06(Sd)	N/A	Kobe Univ.
Thermal properties	Heat capacity	differential scannning calorimetry(DSC)	1mg	10mg	N/A	Nagoya Univ.
	Thermal diffusivity	lock in thermography, laser spot periodic heating radiation thermometry	ϕ1×0.2（Rd)	ϕ3×0.6(Rd)	two-sides	Nagoya Univ AIST
Electrical properties	resistivity	frequency-impedance measurement	ϕ1×0.5(Rd)	ϕ3×1.0(Rd)	two-sides	Kyushu Univ.
	relative permittivity	frequency-impedance measurement	ϕ1×0.5(Rd)	ϕ3×1.0(Rd)	two-sides	Kyushu Univ.
Magnetic properties	susceptibility	ac & dc susceptibility	ϕ0.1(Sd)	ϕ1.0>(Sd)	N/A	Univ. Tokyo
	saturation magnetization	hysteresis loop	ϕ0.1(Sd)	ϕ1.0>(Sd)	N/A	Univ. Tokyo
	saturation remanence	hysteresis loop	ϕ0.1(Sd)	ϕ1.0>(Sd)	N/A	Univ. Tokyo
	coercivity	hysteresis loop	ϕ0.1(Sd)	ϕ1.0>(Sd)	N/A	Univ. Tokyo
	coercivity of remanence	back field demagnetization	ϕ0.1(Sd)	ϕ1.0>(Sd)	N/A	Univ. Tokyo

Table 1 Physical properties list prepared for the measurement of the Ryugu sample. Size requirement is rectangular shape (Rec:three sides lengths) approximation, disk shape approximation (Rd: diameter and thickness), and spherical shape approximation (Sd: diameter),

Result: All of sixteen physical properties (six for mechanical, two for thermal, two for electrical and five for magnetic properties) were measured successfully[2] . In this report, we describe overview of characteristics for each category.

Mechanical properties are key parameters for impact simulation for collisional history of the Ryugu. It is also of great interest to investigate physical mechanism how the large crater of 10m in diameter could be generated by the Small Carry on Impactor (SCI) experiment conducted during the mission phase[5].

The Young's modulus and Poisson's ratio obtained from elastic wave velocity and nanoindentation tests are 5.3-7.3 GPa and 0.122, respectively, which are smaller than those of carbonaceous chondrites[6]. These elastic properties suggest that Ryugu is weaker in strength than carbonaceous chondrites and has a larger volume change upon deformation such as compression and impact.

Thermal properties are not only key parameters to elucidate the thermal evolution of Ryugu, but also important to compare the result from remotesensing observations[7][8]. The thermal inertia of the sample was 892 ($J\ m^{-2}\ s^{-0.5}\ K^{-1}$) at a temperature of 298K calculated from the products of measured thermal diffusivity($3.2\times10^{-7} m^2s^{-1}$), bulk density ($1820 kg/m^3$) and heat capacity($866\ Jkg^{-1}K^{-1}$) respectively. This value is similar to CM2, however, more than three times larger than the mean thermal inertia on the Ryugu surface obtained from remote sensing observations [7][8].

Electrical properties are likely to reflect the bulk abundance and structure of the conductive minerals and the presence of water. Comparing the resistibility of Ryugu (2.5×10^6 ohm・m) with meteorite data[9], it is similar to CM meteorites.

Magnetic properties reflect bulk amounts of magnetic minerals (magnetite, pyrrhotite) and the magnetic characteristics of Ryugu are similar to those of CI meteorites[10].

The overall characteristics of the physical properties indicate that there are no meteorites that match the physical properties of Ryugu, but some properties are similar to CM and others are similar to CI.

In conclusion, it was a great success for us to meaure the physical properties of direct returned sample from small asteroid material for the first time. Our programmatic measuremens taking care of sample damage was also well functioned. Based on this acitivity, we expect to develop the measurement technique in order to apply any sample conditions and sample amount for future upcoming sample return missions.

Acknowledgments: We thank Shimadzu Corporation for experimental corporation of nanoinden and thermal expansion measurement.

References:

[1] Yada T. et al. (2022) Nature Astro., https://doi/org/10.1038/s41550-021-01550-6, [2] Nakamura T.et al.,(2022) , Science submitted,[3] Nakashima D. et al.,(2022) 53^{th} LPSC abstract (this volume), [4] Kurosawa K. et al.,(2022) 53^{th} LPSC abstract (this volume), [5] Arakawa M. et al.,(2020) Science, 368, 67-71, [6] Ostrowski D. and Bryson Y.(2019), PSS, 165, 148-178, [7] Shimaki Y. et al.,(2020) ICARUS, 348, 113835, [8] Grott M. et al.,(2019) Nature Astro. 3, 971-976, [9] Brecher A. et al.,(1975) EPSL, 28,37-45, [10] Rochette P. et al.,(2008) MPS, 43-2, 959-980