Title	6-2 Of Present and Future Space Structures, Their Materials and Construction(Session 6 : What We Can Do for The Future Structures,SIMAP'88 Proceedings of International Symposium on Strategy of Innovation in Materials Processing-New Challenge for the 21st Century-)
Author(s)	Kitamura, Katsuhide
Citation	Transactions of JWRI. 1988, 17(1), p. 209-222
Version Type	VoR
URL	https://doi.org/10.18910/4847
rights	
Note	

Of Present and Future Space Structures, Their Materials and Construction

Katsuhide KITAMURA

Space Development Division, Ishikawajima-Harima Heavy Industries
229,Tonogaya,Mizuho-machi,Nishitama-gun,Tokyo 190-12, Japan

Abstract

Space structures from now to 21st century are reviewed. Characteristics of related structures including rocket, satellite, large space structure and space station are described. Requirements for space use materials, newly developed alloys and advanced composite materials including FRP and FRM are discussed. Material applications to space structures are exemplified and space construction is forseen.

KEY WORDS: (Space Structure)(Space Transportation System) (LSS) (Advanced Composite Material)(Space Construction)

1. Introduction

Present and future scenarios of space infrastructure are proposed in various ways according to their construction technology, targeted calendar year, applicable development steps, available budget scale and so on. An example of scenarios considered in Japan for the beginning of twenty first century is illustrated in Fig.1(ref.1). The completion of the first and second phases are targeted at the end of 20th century and the beginning of 21st century respectively. For manned experimental and observatory systems in the first phase, the First Material Processing Tests (FMPT) by Space shuttle / Spsce lab and Japan experiment module (JEM, 1995) in U.S. Space station (SS) are proceeded. For unmanned systems, on the other hand, various satellite techniques, FMPT / JEM integrated technique, space tests on platforms and observatory free flying units are planned to be developed. For supporting systems, Space shuttle and H-II Rocket (1992) and others, while for telecommunication system, ETS-VI satellite data telemetry are to be utilized. As for the second phase concept, reusable space transportation systems (STS), on-orbit maneuvering vehicle (OMV), orbit Transportation vehicle (OTV) and data telemetry satellite system (SODS) are considered.

This paper first describes structural characteristics of space structures, then discusses requirement for space use materials, and lastly forsees material application to space structures and space construction.

2. Structural Characteristics for Space Structures

2.1 Rocket

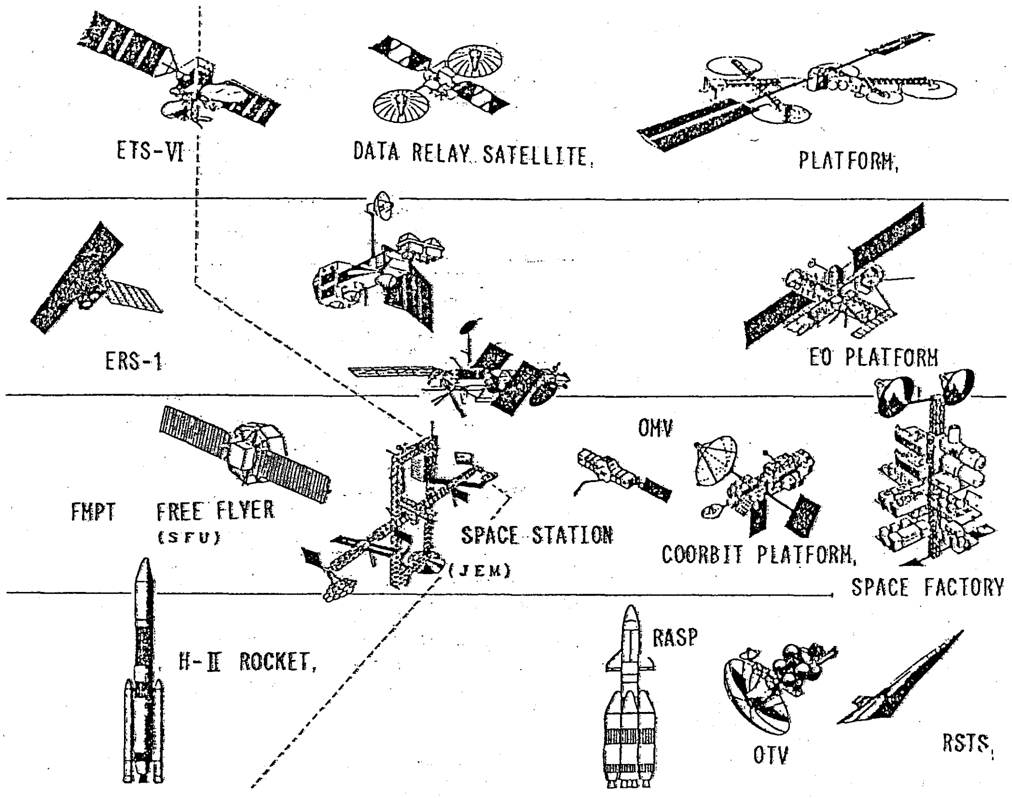

Fig.1 An example of space infrastructure of Japan (ref.1)

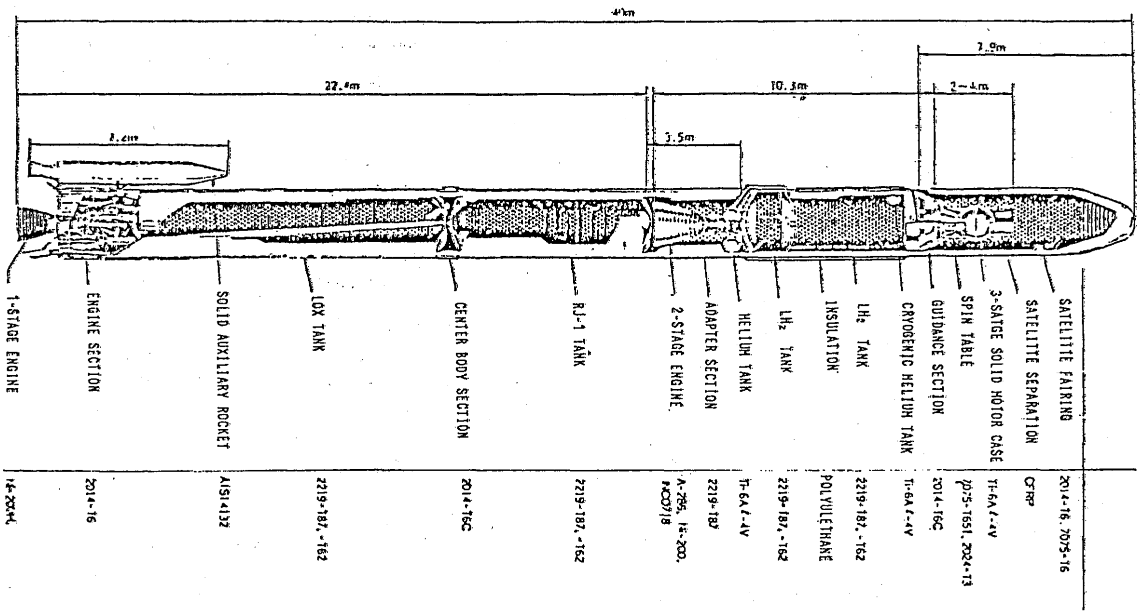

Fig.2 Structural schemes and materials of H-I rocket

A rocket structure has functions of supporting engines, connecting rocket stages, facilitating solid and/or liquid propellant, and supporting or releasing satellites, meanwhile tank pressure, fluid dynamic heating, acoustic and vibration environment are imposed on it. Weight reduction is the primary requirement, which contributes directly to increase in rocket payload performance. Currently servicing Japan's H-I rocket and its structural schemes are illustrated in Fig.2. Liquid rocket tanks are the largest structures in size functioning of propellant accommodation and the rocket main frame simultaneously. A solid rocket motor case accommodates solid propellant and experiences high temperature and pressure in operation. An engine nozzle is exposed to high temperature of engine exhausting gas. A satellite fairing is defined as the section above satellite separation and shields a satellite from air hydrodynamic flow.

2.2 Satellite

A satellite structure has functions of properly supporting various facilities in satellite against the severe static acceleration, vibration, acoustic and shock environment at launch, and fulfiling the mission in thermal environment of orbit maneuvering. In order to allocate launchable weight uppermost to installed facilities, structure weight is strictly controled. Satellite configuration is determined according to the requirements including fabrication on the earth, satellite nesting in rocket fairing, launch load, solar paddle deployment and mission achievement on orbit. Spin stabilizing and three axis stabilizing are two altitude control types, and satellite shapes for the former become sphere, polyhedron near sphere, cylinder or polygon, while for the latter they are freely selected cube or irregular shape attached with solar paddle, which are illustrated in Figs.3 and 4.

2.3 Large space structure (LSS)

A general term LSS is assigned to a large sized structure, promoted to study from future scenarios of space infrastructure, and has major premise to construct themselves on orbit, hence it should be considered different from enhancement of coventional rockets and satellites. Most LSS are proposed to be manned facilities and manned technology is specially indispensable.

LSS concept was first proposed in the study of Large Space System Technology (LSST) led by NASA in the second half of 1970's, where a high rigidity truss, a low rigidity plane structure and a high accuracy generated surface structure were three categories of the objectives. The high rigidity truss is for a science experiment platform (SASP) and a space station (SOC), which are respectively unmanned and manned space systems attached by science mission payloads and electric power/data communication, and finally integrated to NASA space station plan. The low rigidity plane structure is for large-sized solar cell panel generating from 25KW(20m x 20m) to 250KW(100m x 50m) and further growing solar power generation systems (SPS). The high accuracy generated surface structure is for antenna reflecting mirror surface of 10 - 100 meters in length which has missions including communication, Xray astronomy and others.

2.4 Space station (SS)

NASA Space station (SS) is multi-purpose facility to be constructed on circular orbit of 500km altitude using the Space shuttle and has functions of orbit laboratory, service facilities, space transportation transit and logistic station. As illustrated in Fig.5, the main structure consists of truss type double keels and the attached manned area consists of four

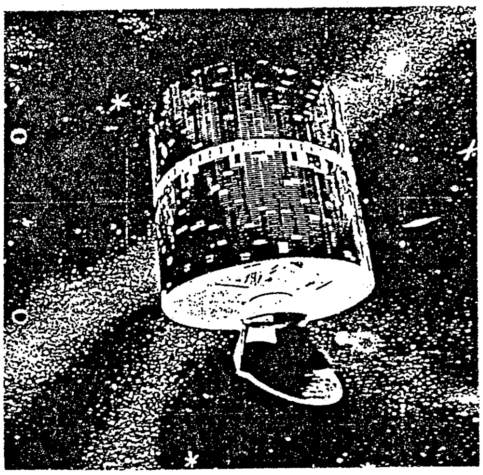

Fig.3 An example of spin stabilized satellite (CS-2)

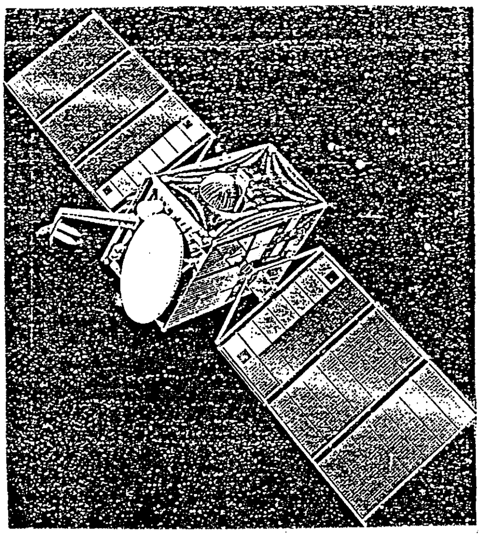

Fig.4 An example of three axis stabilized satellite (ETS-V)

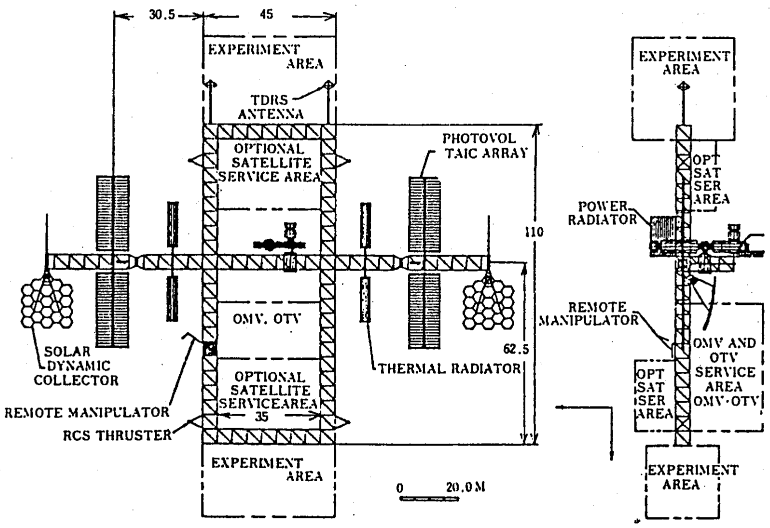

Fig.5 NASA Space Station (ref.2)

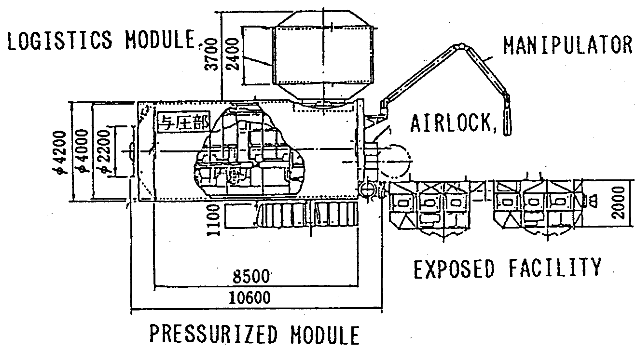

Fig.6 Japan experimental module (JEM) (ref.2)

cylimdrical pressurized modules, where three of them are for experimental purposes and the other habitant purpose, which are located near the center section of the structure. As one part of SS, Japan's experimental module (JEM) consists of a pressurized module, an exposed facility and a logistic part as illustrated in Fig.6.

3. Requirement for materials

Space range where space structures and related mechanisms are being operated is illustrated in Fig.7. In designing structures and mechanisms the requirements from space environment and others should be considered for material selection.

3.1 High vacuum

Vacuum level is high and different according to altitude and most likely considered below 10^{-6} torr. This causes material composition to vary and degrade in strength by evaporation of volatile substances, decreases in creep rupture resistance by loss of gas absorbed layer, increases in friction coefficient and causes difficulty in lubrication.

3.2 Radiation

Ultra-violet ray and X-ray solar radiation destroy chemical composition, and other penetrating radiation, alpha-and beta-particles, and neutron decompose and degrade material surface. Solar radiation level is shown in Fig.8.

3.3 Particlre collision

Due to high energy particles collision including electron, ion and radio particle, atoms and ions project and result in materials degradation. Particles distribution is shown in Fig.9. Degradation by atomic oxygen is currently one of most problematic items. Further by colliding of large mass materials including space dust, meteoroid and debris of space crafts, structure surface is damaged and penetrated. Debris distribution is shown in Fig.10.

3.4 Thermal environment

High temperature: from outside, solar heat (0.12 Btu/ft^2 s at the earth surface), aerodynamic heat due to air resistance at launch and reentry, and from inside, heat generation of rocket engine, electric apparatus and electronic mechanisms. Cryogenic temperature: from outside space sink of 0k, and from inside cryogenic liquid propellants of LH_2 and LOX. It is normal for a space craft structure to experience temperature ranging between -150° - 200°C on orbit.

3.5 Low gravity acceleration

Grabity acceleration is low level and less than 10^{-5}g at altitude of 500km for space station, and considered to have no harmful effect on materials.

3.6 Dynamic environment

Dynamic loadings at launch and reentry generally are refered to hardwares design, including acceleration, vibration (sinusoidal and random), acoustic and shock loads. An example of environment condition is shown in Table.1.

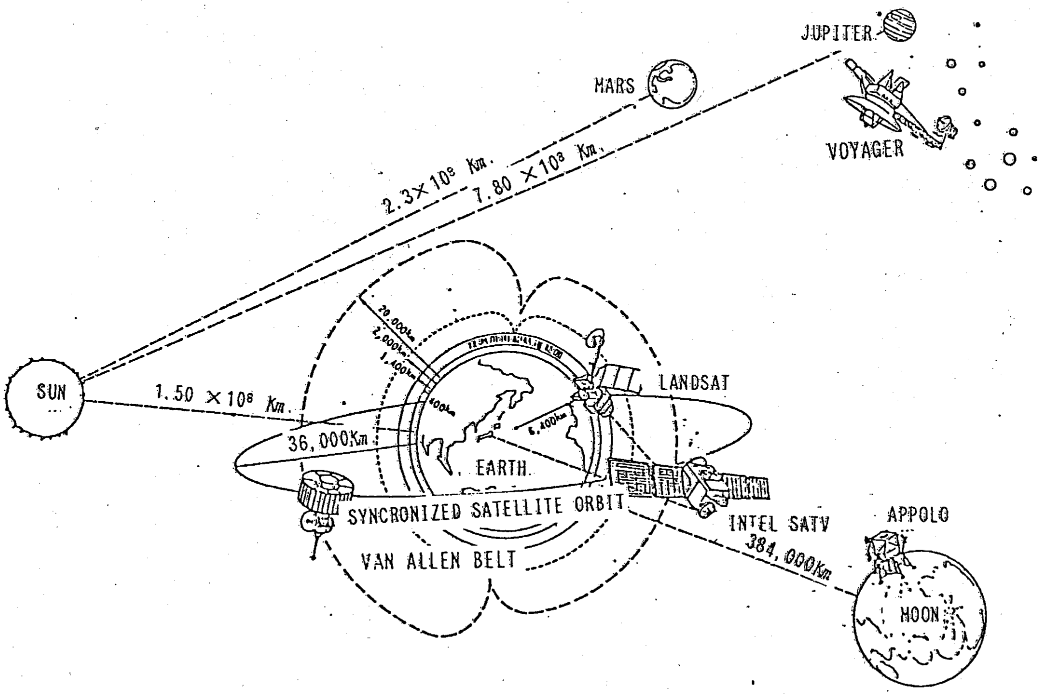

Fig.7 Concept of space utilization range

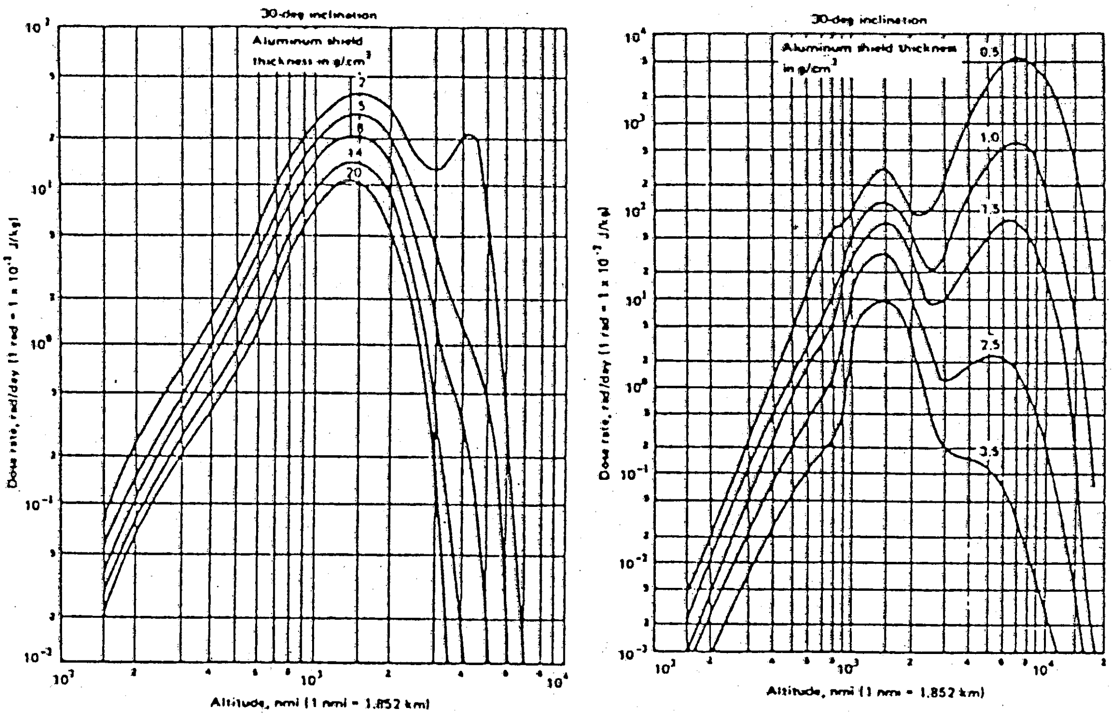

Fig.8 Radiation does rates of captured protone and electron (ref.3)

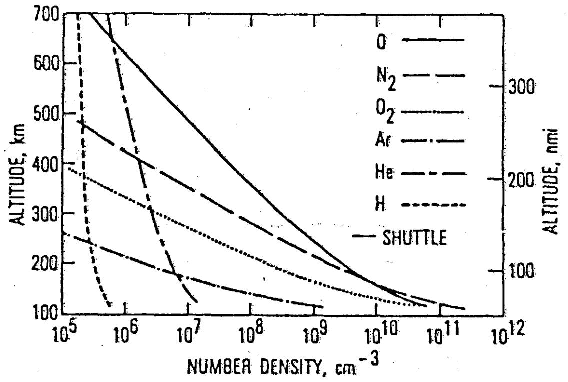

Fig.9 Composition of the atmosphere in low earth orbit (ref.4)

Table 1 An example of space environment

Pressure	10^{-11} torr
Temperature	483 to 75 K (+210°F to −325°F)
Rate of change of temperature	22 K/min (36°F/min)
Humidity	to 70% RH
Linear acceleration	6 g max
Acoustics	15 min at 149 dB overall
Random vibration	0.10 g^2/Hz max
Sine vibration	0.4 double amplitude 5-20 Hz
	8.5 g 20-100 Hz
	6.3 g 100-2,000 Hz

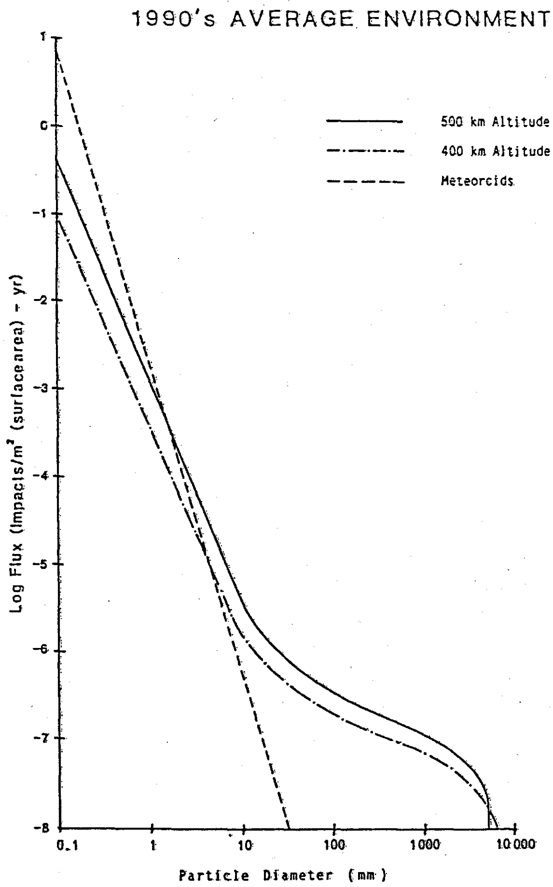

Fig.10 Distribution of debris and meteoroids

Table 2 Properties of various alloys

MATERIAL	ALLOY STATE	DENSITY ρ g/cm³	MECHANICAL PROPERTIES R.T. TENS STRE F_{tu} kg/mm²	TENS YIELD F_{ty} kg/mm²	COMPR YIELD F_{cy} kg/mm²	YOUNGS MODULUS E_t 10³kg/mm²	PROPERTY TO WEIGHT RATIOS F_{tu}/ρ 10⁶mm	F_{ty}/ρ 10⁶mm	F_{cy}/ρ 10⁶mm	E_c/ρ 10⁹mm
AL ALLOY	2014-T6 PLATE	2.80	47	41	42	7.5	16.8	14.6	15.0	2.68
	2024-T4 BAR,	2.80	40	30	27	7.5	14.3	10.7	9.6	2.68
	2219-T81 PLATE	2.82	42	31	32	7.6	14.9	11.0	11.3	2.70
	5052-H34 PLATE	2.69	24	16	16	7.2	8.9	5.9	5.9	2.68
	6061-T6 PLATE	2.71	30	25	25	7.1	11.1	9.2	9.2	2.62
	7075-T6 BAR	2.80	53	45	49	7.4	18.9	16.1	17.5	2.64
STELL	4340 125ksi HEAT TR	7.83	88	72	79	20.4	11.2	9.2	10.1	2.61
	4340 200ksi HEAT TR	7.83	141	124	139	20.4	18.0	15.8	17.8	2.61
	AISI 301 ANNEALING	7.92	53	21	25	19.7	6.7	2.7	3.2	2.49
	AISI 301 1/2 HARDEN	7.92	105	77	21	18.3	13.3	9.7	2.7	2.31
	17-7 PH RH950	7.64	141	127	133	21.1	18.5	16.6	17.4	2.76
	17-7 PH TH1050	7.64	124	105	111	21.1	16.2	13.7	14.5	2.76
	18Ni-8Co-5Mo	7.83	176	169	(169)	19.7	22.5	21.6	(21.6)	2.52
TI ALLOY	6Al-4V ANNEALING PL	4.43	91	84	89	11.5	20.5	19.0	20.1	2.60
	6Al-4V HEAT TR PL	4.43	110	101	107	11.5	24.8	22.8	24.2	2.60
	5Al-2.5Sn ANNEALING	4.48	84	77	81	10.9	18.8	17.2	18.1	2.43
MG ALLOY	AZ31B-H24 PLATE	1.77	27	20	17	4.6	15.3	11.3	9.6	2.60
	HK31A-H24 PLATE	1.78	24	18	14	4.6	13.5	10.1	7.9	2.58
NI ALLOY	Inconel X	8.30	109	70	70	21.8	13.1	8.4	8.4	2.63
BERYLLIUM	Be HEAT ROLLING	1.83	53	40	40	30.9	29.0	21.9	21.9	16.89
	Be HEAT FORGING	1.85	28	19	19	29.9	15.1	10.3	10.3	16.16
CF	CFRP	1.60	160	—	—	13.0	100	—	—	8.12

4. Present and Near Future Material Speculation for Space Structures

4.1 Metal

Primary metallic materials utilized in space structures are light alloys, steels , and for high temperature use, heat-resisting steels and alloys. Material properties of alloys are shown in Table 2.

1) Light alloys

Aluminum alloys including high strength Al-Cu(2014,2024 and 2219), Al-Zn-Mg(7075), corrosion resisting Al-Mn, and Al-Mg, are in low specific weight, high in thermal/electrical conductivity, corrosion-resisting, and are used as general structural materials. Recent development of new alloys is unlimited to pursuit high performance suitable to space structures. For aluminum alloys to improve resistance to brittle and stress-corrosion cracking, 2124 and 2224 are obtained from 2024, and 7150, 7175 and so on from 7075. Al-Li base powder alloys are expected to be next generation materials for space. Due to increase of young's modulus, decrease of specific weight (about 10%), they are reported to reduce the structural weight about 7%, which can compete well with Titanium alloys.(ref.5)

Titanium alloys including Ti-6Al-4V are excellent in heat and corrosion-resisting, and play a main role in material development for space structures. Titanium alloy parts are made by forging and machining, resulting in high cost.

Hence research and development are carried out in following manufacturing processes, (1) super plastic formation-diffusion bonding, (2) constant temperature forging, and (3) hot isostatic pressing (HIP). Magnesium alloy is restricted in cold forming and weak in corrosion-resisting, but easy for chemical milling. Beryllium is low in specific weight, high in rigidity, tensile strength and specific heat, hence used for structure as well as heat shieling.

2) Steels

Low alloy steel, Cr-Mo steel (AISI 4130), Ni-Cr-Mo steel (AISI 4340) and maraging steel, and 18% Ni steel have high strength. Austenitic stainless steels (AISI 301) are excellent in strength and corrosion-resistance, while free from low temperature brittleness. Age hardening stainless steel 17-7PH and so on are also excellent in strength and corrosion-resistance.

3) Heat-resisting steel and alloys

Heat-resisting steel and alloy are strengthened against creep, oxidation, thermal fatigue and thermal shock. Related to ambient temperature, martensitic heat-resisting steels are utilized in temperature below 550°C, austenitic iron base alloys are used below 700°C, and further nickle or molybdenum base alloy including 20Cr-Ni (Nimonic), 15Cr-Fe-Ni (Inconel), and Mo-Fe-Ni (Hastelloy) are used for temperature exceeding 700°C.

The development targets for high performance alloys of Basic Industrial Technology for Future Industries-Metals and Composites Technology sponsored by the Japanese Gavernment are (1) super heat resisting alloy:tensile strength of $14 kgf/mm^2$ and elongation of 10% at 1040°C, (2) heat resisting, toughness alloy:tensile strength of $160 kgf/mm^2$ and elogation of 20% at 760°C, (3) light weight, toughness alloy:specific weight of above $28 kgf/mm^2/g/cm^3$. For three targets of Metals Technology, uni-cristalized alloy, super plastic alloy of Ni base at 700 - 800°C and Ti base at 300°C, and powder dispersed alloy have been researched respectively.(ref.7)

4.2 Composite materials

Composite materials have preferable characteristics of high specific strength, heat-resisting and strongly directional, which are classified in fiber and particle as to reinforcing material, and also in plastic, metallic and ceramic as to matrix material.

1) Fiber reinforced plastics (FRP)

FRP are typical materials used for space structures. For fibers glass (G), graphite (Gr) or carbon (C), boron (Br), alamide (Kevlar) and others are used, while for matrix plastic resins primarily epoxy (Ep) is used, followed by polyimide, polysulfone and phenol, because of low specific weight and good bonding to fibers. Epoxy is thermo-setting, polyimide and other aromatic family are good in insulating, phenol has relatively high in heat-resisting characteristics, Ep resin FRP are GFRP, CFRP (GF/Ep), BFRP (Br/Ep) and KFRP (Kevlar/Ep). Examples of material properties are shown in Table 3. GFRP is low in rigidity, and limited to secondary structures, while advanced composite materials (ACM) including CFRP and BFRP, are developed for high rigidity and strength, hence applied to primary structures. CFRP is very low in heat expansion modulus and suitable for space structures under severe thermal variation. As for special cases SiC/phenol is ablative and utilized in heat-resisting part of rocket nozzle exposed in about 2500°C combustion gas.

Recent development targets of FRP are (1) to increase heat-resisting and binding properties of high strength Gr/Ep, (2) to obtain forming technology of super heat-resisting polyimide resin, and (3) to newly develop heat-resisting/thermoplastic resins. In the abovementioned Metals and Composites Technology, currently, Ep resin with thermal decomposition temperature of above 300°C and polyimide resin with that of above 400°C are developed, and being manufactured with T-400 fiber, to one axis CFRP, their tensile strength exceeds 200 kgf/mm^2 at 200°C and 250°C respectively.(ref.8)

Related to manufacturing process, research has established practical techniques for continuous manufacturing of thin, long and precise tubes and frames to apply basic parts for space structure. NASA has developed polyimide resin which is able to manufacture at 350-400°F similar to Ep resin, increased properties of Ep resin for the primary aircraft structures, and further developed heat-resisting resin for use above 700°F suitable for space structures. Thermoplastic resin PEEK was developed in England, which has a good strength and rigidity retained ratio, and energy release of Gr/PEEK is one order larger than Gr/Ep. FRP is weak in resistance to not only temperature but atomic oxygen. One example of resisting test result of resins against atomic oxygen is shown in Table 4. For material used in structures which are expected to stay in space for long period extensive investigation must be conducted to prove stability and safety before its application.

2) Fiber reinforced metals (FRM)

FRM are composed of heat-resisting metals and reinforcing fibers. In fiber reinforced type carbon fiber (CF), SiC fiber, and Br fiber are used, while for matrix metals aluminum, titanium, magnesium nickel and their alloys are utilized. For high temperature application, Thoria (ThO_2) reinforced tungsten fiber is combined with Ni base alloy. In particle reinforcing type precise particles not reacting to matrix metal in high temperature are dispersed. In SAP alloy Al_2O_3 is dispersed into aluminum, and in TD-Ni alloy ThO_2 dispersed into Ni-Mo, and Ni-Cr alloys.

In the abovementioned Metal and Composites Technology, currently both aluminum infilterated graphite and SiC (Nicalon) yarn can be manufactured

Table 3 Properties of fibers and epoxy resin (ref.6.)

		EPOXY	E-GLASS	CARBON	BORON	ALAMIDE (KEVLAR 49)
FIBER RAD	(μm)	—	10	7~8	100	10
SPECIFIC WEI		1.1~1.2	2.5	1.8	2.6	1.4
TENSILE STR	(N/mm²)	80~90	1,800	2,500	3,200	2,600
YOUNGS MOt. L	(N/mm²)	3,500	74,500	570,000	420,000	133,000
C		—	74,500	5,700	420,000	7,000
SHEARING MOD	(N/mm²)	—	29,800	17,800	17,300	12,000
POISSONS RAT		0.35	0.25	0.39	0.27	0.3
ELONGATION	(%)	3~5	1.5	0.5	0.5~0.8	2
THER EXP M L	(1/°C)	66×10^{-6}	4.8×10^{-6}	-0.5×10^{-6}	1.5×10^{-6}	-6.0×10^{-6}
C		〃	〃	5×10^{-6}	〃	75×10^{-6}

Table 4 Reaction properties against atomic oxygen (STS-8) (ref.4)

HOW ORGANICS REACTED. DATA MAINLY FROM STS-8 EXPERIMENTS

Material	Reaction Efficiency, cm³/atom × 10⁻²⁴
Kapton	3.0
Mylar	3.4
Tedlar	3.2
Polyethylene	3.7
PMMA[a]	3.1
Polyimide	3.3
Polysulfone	2.4
1034C epoxy	2.1
5208/T300 epoxy	2.5
Teflon, TFE	<0.05
Teflon, FEP	<0.05

[a]PMMA is Polymethylmethacrylate.

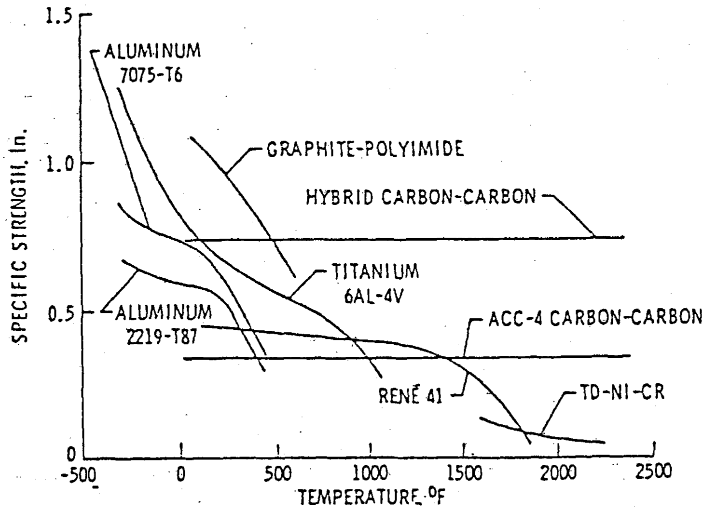

Fig.11 High temperature strength of various materials (ref.9)

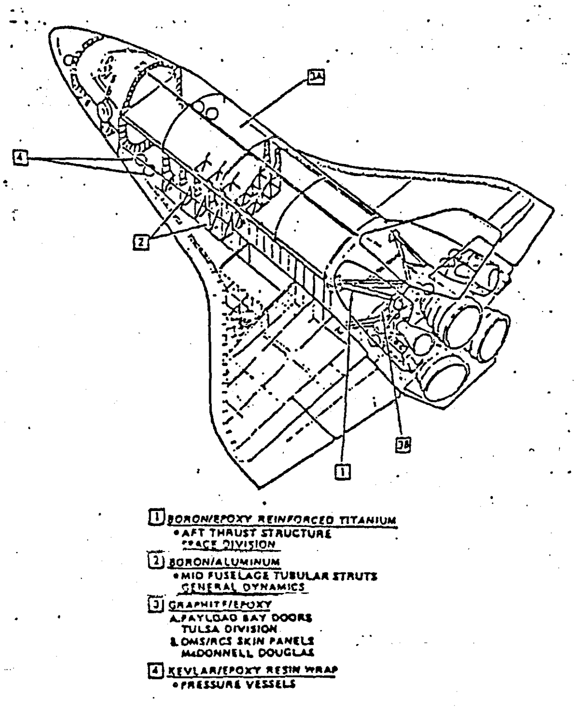

Fig.12 Composite materials of Space shuttle orbiter

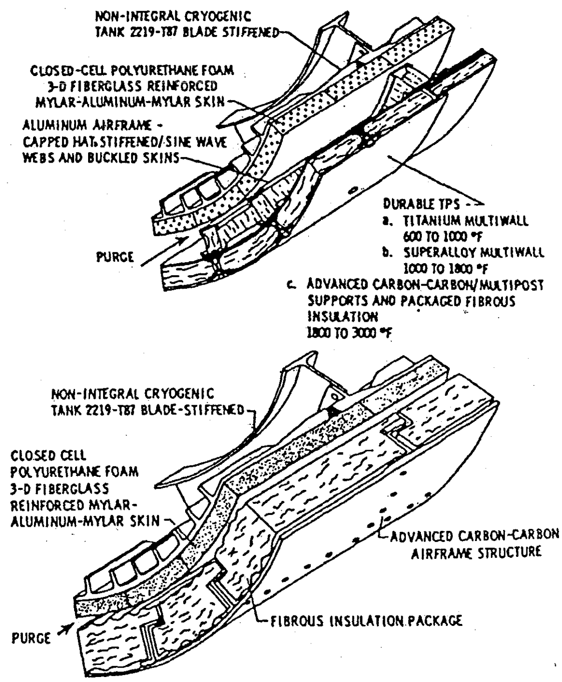

Fig.13 Airframe and tank structures of advanced STS (ref.10)

continuous 100 meter wire preform, which has tensile strength of 150 kgf/mm^2 till 450°C. Related to manufacturing process, research has proceeded to develop basic techniques for mainly aircrafts and turbine engines application. Press, roll, HIP and other equipments and machines applicable to materials and structure types have been developed for production of one directional FRM which are composed of CF, SiC and Br long fibers of whiskers as reinforcing and aluminum or titanium alloys as matrix. (ref.8)

3) Fiber reinforced ceramics (FRC)

Ceramic oxides containing Al_2O_3 have excellent in heat-resisting properties, but are sensitive to thermal shock leading to failure. FRC are composed of ceramics as matrix and Ni-base and Ni-Co-base alloys fibers or sheets are used as high fracture toughness reinforcing elements. Carbon-carbon (C/C) is made by phenol resin CFRP, which is decomposed by heat and again transformed into graphite. Gr is superior in friction waste-resisting and heat resisting but inferior in fracture toughness, therefore transformed to highly strengthened C/C due to fiber reinforcing, and applied as excellent structural materials. Comparison on high temperature strength of materials utilized in space structures is shown in Fig.11.

5. Application to Space Structures

5.1 Rocket

Rocket primary structure is made of stainless steel, Al-, Ti- and Mg-alloys due to its thermal requirements, one example of which is already shown in Fig.2. Solid rocket motor case is made of low alloy steel 4130 and so on and FRP (filament winding) due to specific weight, weldability, fracture toughness and corrosion resistance. For fairing, protruding parts and front surface of reentry ablation material is necessary against hydrodynamic heating. Composite materials are partly applied to rocket primary structures and considered rapid increase of their application.

5.2 STS

Space shuttle orbiter utilized ACM in many secondary structures, examples of which are shown in Fig.12. Payload bay door is 18.3m x 4.6m sandwitch structure which is made of Gr/Ep skin and normex honeycomb, aft. thrust structure is of Br/Ep, pressure vessels are of metal reinforced by K/Ep (filament winding), and mid. fuselage struts connecting bottom to payload bay are of Br/Al tubes formed by HIP. Application of FRP and FRM resulted 44% weight reduction from base line. Thermal protection system consists of reusable surface insulators (RSI) made of ceramic materials. To next generation STS orbiter non ablative, advanced C/C is proposed to apply, of which structure concepts are exemplified in Fig.13.

5.3 Satellites

Depending on their functions various materials are used for satellites, but except where electro-magnetic shielding and thermal conductivity are problematical composite materials, especially CFRP become most frequently utilized for their structures. Examples of materials used in Japanese satellites are shown in Fig.14. In planet A primary structure thrust tube and struts are made of CFRP, substrata are of KFRP, while uni-block forming cylindrical panel is of Al honeycomb sandwitch. Thrust tube was so far made of Al alloy, Mg alloy or GFRP, but using of CFRP results about 30% weight reduction. Light weight solar paddle is frequently made of CFRP rectangular section tube and CF sheet/Ep blanket.

5.4 Platform, space station and so on

SPAS is scientific experiment platform developed by NASA and West Germany. Its primary structure is truss composed of 70 cm Gr/Ep high rigidity pipes and Ti alloy joints. A basic truss-type structure which is 1.5m long, 0.75m wide and 0.75m high was manufactured simulating JEM's primary structure, where joint blocks as well as pipes are made of CFRP as shown in Fig.16. Space station shall be constructed with CFRP pipe truss elements. Construction scenarios by manned extravehicular activities (EVA) are now under discussion.

6. Construction of LSS in Space

Construction technique of LSS including space station is classified into three concepts of deployment, erection in initial phase and fabrication in space in enhanced phase.

6.1 Deployment and erection

In order to increase transportation effectiveness structure is folded in transportation vehicle and automatically deployed to necessary configuration, where folding and deploying mechanism is so complex that applicable cofiguration is restricted. Usually solar paddle of satellite uses this concept. A mechanism model of deployable truss simulating structure parts of JEM in next phase was constructed, and deployment test was conducted from 0.2m to 3.2m in height as shown in Fig.17.

On the other hand, structure is divided into structure elements, piled in heaps in transportation vehicle and erected by men to necessary configuration in space. Safety assurance in EVA becomes severest requirement.

6.2 Fabrication in Space

Related to structure generation in space structure element fabrication and connection techniques are necessary. Raw material rolled sheet is transported, and fabricated to frame elements by automatic frame builder and, which was facilitated for Al alloy elements as illustrated in Fig.18, and also planned for FRP elements

Element joints are processed by welding including spot welding, supersonic welding and so on. Spot and supersonic weldings are applied to Al alloy and FRP frame elements respectively. Moreover bonding may be applied but degradation in space environment is problematic. For erection of structure elements mechanical joint method is generally utilized from view point of connecting and disassembling capabilities. For repair against failure of structure members and leakage of pressure vessels, line welding is necessary as repair technique to assure strength and shield. Both electronic beam and laser weldings are considered effective for space use, and have not any factors unconvenient for space environment.

7. Conclusion

This paper describes a trend of present and future space structures, their materials and construction as follows.

1) In the future scenario of space infrastructure proceeding to 21st century, new types of space crafts and structures are to be developed.

2) Rocket, satellite and space craft are strengthed their performance and scale. Large space structures (LSS) are required to reduce their weight.

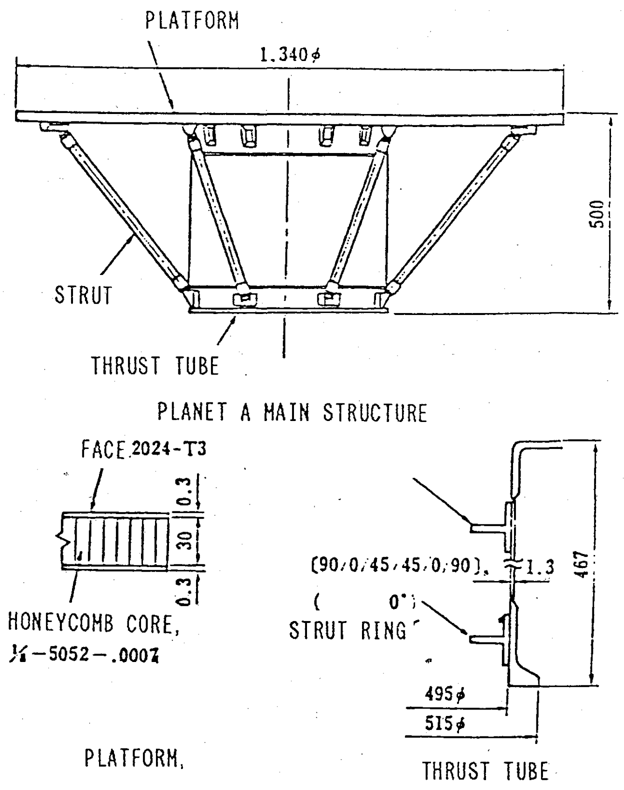

Fig.14 Planet A main structure

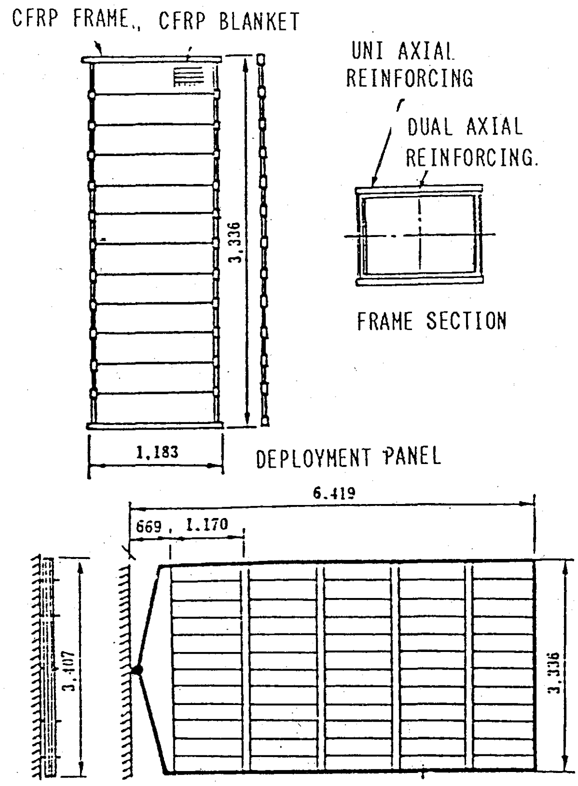

Fig.15 Light weight solar paddle

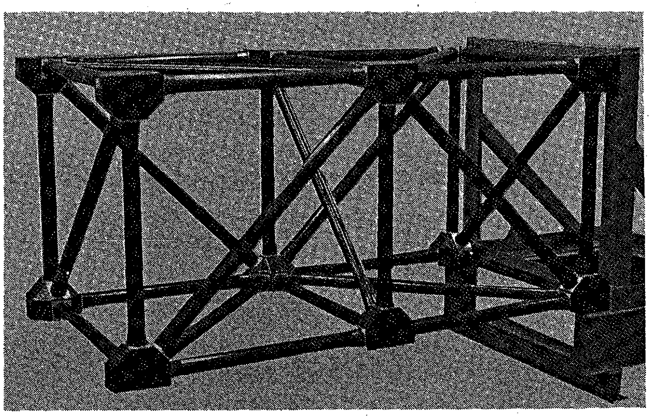

Fig.16 An example of CFRP truss structures (ref.11)

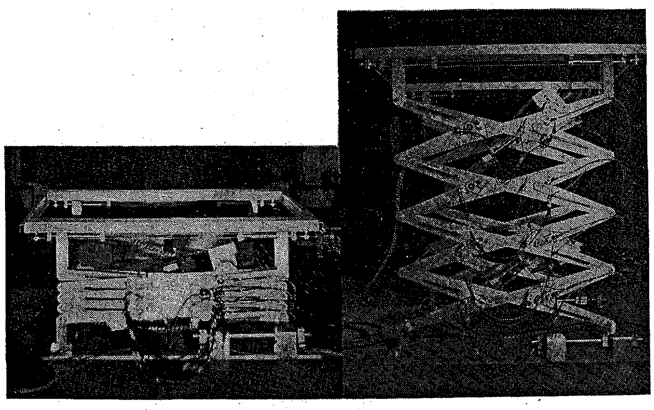

Fig.17 Mechanism model of deployable truss (ref.12)

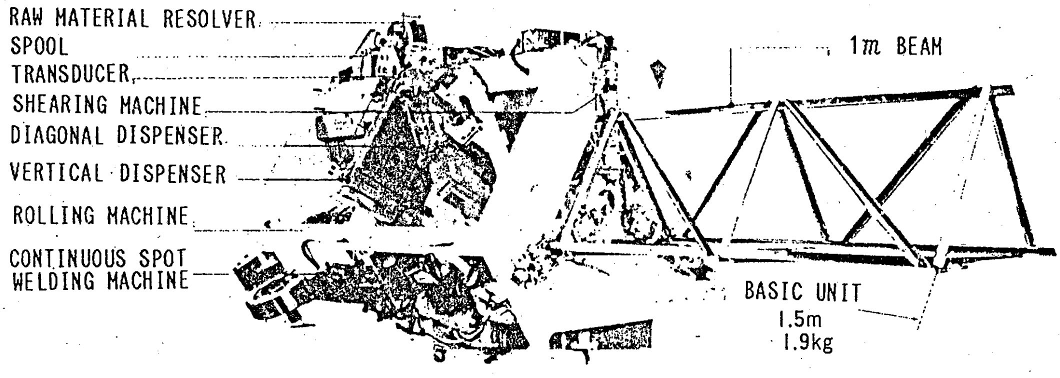

Fig.18 Automatic frame builder (ref.13)

3) In selecting materials precise consideration of space environments is requested. Especially degradation by atomic oxygen must be estimated for structures which stay in space for long period.

4) As for space use materials, from usual metallic and composite materials new alloys and ACM including CFRP and FRM are developed.

5) In application examples of newly developed materials CFRP to primary structure and Carbon/carbon to heat-resisting structure are notable.

6) In space construction of LSS deployment, erection and fabrication in space are forseen. Both electronic beam and laser weldings are considered effective for space use.

References

1) Godai,T.: Space Infrastructure Longterm Concepts Proc. 3rd Space Station Conf.,April(1987),P.27(in Japanese)
2) Siraki, K.etal.: Preliminary Design of Experiment Module in Space Station, Proc. 2nd NASDA Technology Conf.,(1986) (in Japanese)
3) Koura, K,etal.: Space Radiation and Solar Radiation Proc. 2nd Manned Space Sci.Symp.,Jan.(1988),P.6 (in Japanese)
4) Fujimori, Y.etal: Atomic Oxygen, Meteoroide and Debris, ditto, P.2 (in Japanese)
5) Baba, Y.etal.: Recent Development in Aluminum Alloys for Aerocraft, J.Japan.Soc.Aero.Spa.Sci., Vol.32, No.367(1984), P424(in Japanese)
6) Kobayashi, A.: Advance Composites-Present Status and Future Trend, ditto,P.456 (in Japanese)
7) Proc. 2nd Symposium of Basic Industries Technology for Future Industries-Metals and Composites Technology, 1984 (in Japanese)
8) Minoda, Y.: Sumary, Research and Development of Advanced Composite Materials, Proc. 4th ditto, 1986 (in Japanese)
9) Taylor, A.H.etal.: The FSTS Study, Structures and Subsystems, Astronautics and Aeronautics, June(1983), P.50
10) Taylor, A.H.etal.: Structural Concepts for Future Space Transportation System Orbiters, J.Spacecraft, Vol.22, No.3(1985), P.333
11) Yamaguchi, M.Kitamura, K.etal.: Development of Graphite Epoxy Space Structure, Proc. 15th Int.Symp.Spa. Tech.Sci.Vol.1 (1986),P.509(in Japanese)
12) Kitamura, K.etal.: Mechanism Model of Deployable Truss, Proc. JSASS/JSME Structures Conf. Vol.29 (1987),P.186 (in Japanese)
13) Miura, K.: Construction Techniques of LSS in Space, Space Technology Utilization Knowledge (1982), P.63 (in Japanese)