TECHNICAL NOTE

EVOLUTION OF AIRFRAME MATERIALS FOR RUSSIAN FIGHTERS

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Abstract

Fighter aircraft make extensive use of materials such as Steels, Aluminum alloys, Magnesium alloys, Titanium alloys and composites for construction of airframe. It has been seen that many of the airframe materials used in Russian fighters are common. But attempt has been made to introduce progressively superior quality alloy grades in the later version of aircraft. A comprehensive study (1) is thus made to identify the important structural member of the airframe and its materials in different generations of the Russian fighters to highlight the ways lighter and superior alloys replaced steels.

This paper describes the application of various aerospace materials used from the evolution of old generation Russian combat fighters to latest Russian fighters. Effort have been made to analyse and explain the change of some of the grades within the domain of these Russian fighters and use of superior structural materials (western and Russian origin) to old age aircraft to enhance the performance. It also discusses the percentage weight change of various types of materials used in the construction of Russian fighter aircrafts under operation in India. Main objective of this study which is discussed here, to keep aware the operators as well as manufacturer's of Russian aircrafts within India to exchange these Russian materials during rationalization, substitution, indigenization and at a times of short supply or non-availability of these grades based on their merits.

Introduction

Indian Air Force has in its inventory different Russian combat fighter aircraft. These fighter aircraft make extensive use of metallic materials during their constructions. It has been seen that many of these materials used in the Airframe are common. However, superior quality grades as well as new alloys have been introduced progressively in the later version of aircraft.

Selection of materials in aircraft construction is rather complex and is based on trade off amongsts conflicting requirements of high strength, low density and ease of fabrication or processing. Aircraft Materials are produced with special melting processes, which are, generally not used in commercial applications. Due to non-availability or short supply of aviation quality materials, often there is hold up in the production as well as repair in service line. The need of the hour is to search for equivalent substitute or superior grade of material from the existing Russian grades or indigenise the same. Also there are instances where the materials are required to be altered due to inherent material problems faced by the user. As on date, 'Materials at a Glance' used in airframe of these Russian aircraft is not available which very often become essential in day to day activities during substitution, indigenisation and rationalisation of materials. An effort is thus made to identify the important structural members of the airframe and its materials for these Russian combat fighter aircraft (1) which are under operation with Indian Air Force.

Russian combat fighter aircraft are discussed in this paper as Russian combat-1, Russian combat-2, Russian combat-3, Russian combat-4 and Russian combat-5 and not by their original name. They have been described in the text agewise as per their year of manufacturing in Russia.

Materials Used in Russian Aircraft

Basic grade of materials used in airframe structural components of Russian Combat fighters are steel, Alu-

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minium alloys, Titanium alloys, Magnesium alloys and other alloys. Major grades of these alloys used in the construction of airframe along with their nominal composition for the reference are enumerated here to get fair knowledge of chemistry (2), since Russian designation of grades are not commonly used like other western specifications. This will help while discussing how the different alloy grades have been introduced progressively in the recent Russian aircraft. Study was carried out to identify the materials used in various sections/components of different versions of Russian aircraft from scattered data from various technical descriptions, overhaul manuals, Russian specifications and literature (3, 4). However, summary of this study was tried to present in Table-1 in a broad respect as different materials used structurally for various sections of Russian aircraft. Mechanical properties of some of the important airframe materials are placed at Table-2.

Aluminium Alloys

Aluminium alloys form the major airframe material. Extensive use of these alloys is accounted for their high strength to weight ratio, ease of fabrication, reasonable good corrosion resistance, weldability etc. Major alloys used in the Russian combat fighters include both Wrought and Cast Aluminium alloys from Non-heat treatable and heat treatable grades.

Non-Heat treatable alloys include AMG series Al-Mg alloys (Mg - 2%, 3%, 4% 5% and 6%), AMSch series Al-1.2Mn alloys and cast alloys AL9 (Al-7Si).

Heat treatable alloys include **Duralumins** [D1(Al-4.3Cu), D16(Al-4.Cu-1.5Mg-Mn), D19(Al-4.3Cu-2.0Mg-Mn-Be), D19PCh(Al-3.5Cu-2.3Mg-Mn-Be), (D20 (Al-6.5Cu-Mg-Mn) and B65 (Al-4.3Cu-Mg-Mn)], **Forging alloys** [AK4(Al-2.2Cu-1.6Mg-1Ni-1Fe-Si), AK4-1(Al-2.3Cu-1.5Mg-1Ni-1Fe-Ti), AK6(Al-2.3Cu-Mg-Mn-1Si), AK8(Al-4.4Cu-Mg-Mn-1Si)], **High strength Al-Zn alloys** [B93(Al-7Zn-1Cu-1.8Mg), B93PCh(Al-7Zn-1Cu-1.8Mg-Fe,Si impurities restricted), B95(Al-6Zn-1.7Cu-2.3Mg-Mn-Cr), B95PCh(Al-6Zn-1.7Cu-2.3Mg-Mn-Cr -Fe,Si impurities restricted)], Aluminium Lithium alloys [1420 (Al- 2Li -5.5Mg -Zr)], **Cast alloys** [Al5(Al-5Si-1.2Cu), Al7(Al-2Si-4.5Cu), AL19 (Al-5Cu-Mn).

Improvement in Duralumins

Duralumin alloy, grade D16 is widely used in Russian fighter series of aircraft. Components made from this alloy include panels and other sheet-metal parts, stampings, extruded profiles and machined parts fabricated from bars etc. It may be seen from the Table-1 that grade D16 is completely replaced by D19 and D19Ch in later version of aircraft. Chemistry as well as mechanical properties of D19 is comparable to D16 except that it contains beryllium (0.0002-0.005%) which contributes certain improvement in the property. D19 is fairly ductile in annealed and just hardened condition as compared to D16 alloy. Total corrosion resistance of D19 and D16 are the same but when heated to 150-250^{o}C, D19 shows lesser tendency towards intercrystalline corrosion. Weldability by spot welding of D16 and D19 are same but weldability with argon arc welding of D19 is better than that of D16. Grade D19Ch is marginally superior to D19 due to restricted level of impurities. Grade D19PCh pertains to stampings and forging having superior strength. It is to be noted for the benefit of the readers that German Duralumin grade WL3.1354T351 has also been allowed and airworthy approved (due to its superior exfoliation resistance) to use in lieu of Russian duralumin grades D16T and D19T.

Replacement and Reinduction of High Strength Aluminium Alloy B95

High strength Al-Cu-Mg-Zn alloy, grade B95 is used for fabrication of many important load-bearing components in the airframe Russian combat-1 of mid 60's aircraft. Cold rolled sheet, extruded bar and hot forging are the basic raw materials for this grade. It is found that in Russian combat-2 (late 70's aircraft) and Russian combat-3 (early 80's aircraft), the alloy grade B95 is partially replaced by B93. However, in the subsequent aircraft, Russian combat-4 (mid 90's aircraft) and Russian combat-5 (early 2000's aircraft), this alloy B93 once again is replaced by B95 and B95PCh grades. In B95PCh grade, iron and silicon impurities have been restricted to low levels and tried to equalize the properties in all three directions as compared to similar grade without Pch suffix. Both B93 and B95 are Al-Cu-Mg-Zn alloys of comparable chemistry except that grade B95 contains chromium and B93 contains iron. Forgeability of B93 is better and it shows uniform longitudinal, transverse and short transverse strength. However in respect of notch sensitivity and stress corrosion cracking (SCC), B93 is inferior to that of B95 and B95PCh grade. To improve SCC, Stage ageing treatment is introduced in latest versions of aircraft to B95 grade. This has made replacement of B95 again and B95PCh grade in place of B93 in the subsequent aircraft (Table-1). Also German High strength alloy WL3.4394 is approved by Military airworthiness agency in India to use in lieu of Russian grade B95 in view of the its better SCC resistance.

Introduction of Aluminium - Lithium Alloy in Su-30 Aircraft

Al-Li alloy grade 1420 (Al-2Li-5.5Mg) is introduced in Russian combat-4 (mid 90's aircraft) and Russian combat-5 (early 2000's aircraft). It is seen that in Russian combat-5, it has replaced some of the composite panels being used in Russian combat-4. Alloy 1420 is developed as a new generation grade of low density and high stiffness properties for use in aircraft structures. This is superior because of low density of Li (0.54 gm/cm^3) which means that for each 1% addition, the density of an aluminium alloy is reduced by 3%. Lithium is also unique amongst the more soluble elements in that it cause marked increase in the Young's modulus of aluminium alloy (6% for each 1% added). This Russian grade is lightest (Specific gravity 2.50 gm/cm^3) of Al-Li alloys (5) developed so far.

Steels

Widely used Russian Steel grades in aircraft construction are **Carbon steels** [C-20 (0.2%C) to C-70 (0.70%C)], **Low alloy structural steels** [30Kh GSA(0.3C-1.0Cr-1.0Mn-1.0Si), 30KhGSN2A(0.3C-1.0Cr-1.0Mn-1.0Si-2Ni),16KhGTA(0.16C-1.5Cr-1.0Mn-Ti),16KhGSN(0.16C-1.0Cr-1.0Ni-1.0Si), **Spring steels** 65C2BA(0.65C-2.0Si-1.0W), 50KhFA(0.50C-1.0Cr-V), 60C2A(0.6C-2.0Si), **Stainless steels** 12Kh18N10T (0.12C-18Cr-10Ni-Ti), 14Kh17N2(0.12C-17Cr-2Ni), 2Kh13(0.2C-13Cr), 07Kh16N6 (0.07C-16Cr-6Ni), VNS-2(0.06C-14Cr-6Ni-2Cu-Ti), EP-817 (0.06C-14Cr-6Ni-2Cu-Mo-W) and **Steel Castings** 35KhGSL(0.35C-1.0Cr-1.0Mn-1.0Si), VNL-3(0.08C-14Cr-5Ni-2Mo-1Cu).

Steels grades 30KhGSA, 30KhGSNA/30KhGSN2A are widely accepted structural steel in all Russian aircraft. The chemistry of these alloys has no equivalent in western grade. Ease of fabrication in various forms, good weldability as well as good strength and ductility have made these grades very attractive for wide-use in various elements like load bearing structures, critical attachment units and majority of the fasteners including rivets in the airframe.

Steel grade 30KhGSN2A is a very high strength structural alloy. Among high strength steels (UTS 160 to 180 Kg/mm^2), it has reasonably good weldability and fabricability. It is a proven alloy used for landing gear of all Russian aircraft. Modern melting technique by electro-slag refining and vacuum degassing have further improved the quality of these grades for aircraft application. It has been observed that grades 30KhGSA, 30KhGSNA/30KhGSN2A is used as evergreen alloy in structural applications of all Russian fighters due to its good performance over the years. This alloy or its equivalent chemistry wise is not so far developed or used by any of the western aircraft manufacturers. For similar applications in western aircrafts, strength wise equivalent 4130/4340 grades are used.

Stainless Steel Grade VNS2

Stainless Steel grade VNS2 (08Kh15N5D2T) belongs to the category of precipitation Hardening Steel (nearest equivalent in western grade is French X15U5W (E-Z 6CNU 15.05)). The term precipitation hardening implies from the fact that the final hardening is affected by precipitation of submicroscopic constituents during ageing subsequent to solutionising at 950 -1000^{o}C. The unique property of this grade is that it does not loose its strength significantly when heated beyond its ageing temperature (420 to 630^{o}C). This unique property in addition to resistance to air tightness has made this alloy widely accepted material, weldable after full heat treatment and recommended for fabrication of parts of load bearing elements working in atmospheric condition and in contact with fuel at temperatures up to 300^{o}C. It may be seen from Table-1 that steel VNS2 was not used in Russian combat aircraft of mid 60's while in late 70's and early 80's fighters, many of the load bearing structures and all-metal welded fuel tanks are made from this grade. In mid 90's fighters, VNS2 grade is replaced by steel grade 06Kh14N6D2MBT (EP-817). However, electro slag refined quality VNS2 grade is used to a limited extent such as skin of fuel tank3.

Replacement of VNS2 by Other Alloy in Later Variants

Replacement of VNS2 grade is realized due to the fact VNS2 is prone to stress corrosion crack as has been reported in late 70's and early 80's fighters. In mid 90's aircraft, majority of the VNS2 grade is replaced by another grade of precipitation hardening stainless steel EP-817 (06Kh14N6D2MBT) having same range of strength as that of VNS2 steel (UTS- 135 Kg/mm^2) but differing in more stability towards resistance of welded joints to corrosion cracking under stress and simultaneously high toughness at low temperatures (-70^{o}C) . Use of grade EP-817 have significantly reduced incidence of Stress corrosion cracking on airframe of latest Russian combat fighters.

Table-1 : Summary of materials used structurally in various sections of Russian Aircraft					
Russian Fighter Aircraft					
Alloy	Russian combat-1 (Mid 1960s)	Russian combat-2 (Late 1970s)	Russian combat-3 (Early 1980s)	Russian combat-4 (Mid 1990s)	Russian combat-5 (Early 2000s)
Aircraft Skin					
Fuselage					
Al alloy	D16 AT	D19AT, D19AT	D19AT, B95, 1420	D19, B95, 1420	
Steels		VNS2	VNS2	VNS2 sh, EP-817	
Ti alloy				OT4-1	BT20, OT4-1
Composites				GFRP	
Stabilizer					
Al alloy	D16AT	D19AT	D19AT	D19AT, B95, 1420	B95, 1420
Ti alloy				BT20	
Fin					
Al alloy	D16AT	D19AT	D19AT	1420, D19AT	B95, 1420
Composites				GFRP	
Rudder					
Al alloy	D16 AT	D19AT	D19AT	1420, D19AT	D19ATB, 1420
Wing					
Al alloy	D16AT, B95AT	D19AT, B95	D19AT, B95	D19ChAT, 1420, B95ChAT	B95, D19
Ti alloy				OT4-1	
Composites				CFRP	
Tailcone					
Ti alloy	OT4-1	OT4-1	OT4-1	OT4-1	OT4-1
Steel	AE-703, Kh18N9T	KhN38VT (AE-703)	KhN38VT	-	-
Ventral Fin					
Al alloy	D16AT	D19AT	D19AT		D19, 1420
Composites	GFRP	GFRP	GFRP	GFRP	
Frames					
Al alloy	D16, B95	D19AT, B93, AK4-1	D19AT B93 AK4-1	D19T, B95ch, AK4-1	D19A, B95CH, AK4-1
Steels	30KhGSA	VNS2	VNS2	EP-817	EP-817
Ti alloy		OT4-1	OT4-1	BT20, OT4-1	OT4-1, BT20
Beams					
Al alloy	B95, AK4-1	B93, AK4-1	B93, AK4-1	D19T, B95Ch, AK4-1	AK4-1
Steels	30KhGSA, 30KhGSNA	30KhGSA, VNS-2	VNS-2, 30KhGSNA	30KhGSA, EP-817, 30KhGSN2A	VNS

Table-1 (Contd) : Summary of materials used structurally in various sections of Russian Aircraft

Russian Fighter Aircraft					
Alloy	Russian combat-1 (Mid 1960s)	Russian combat-2 (Late 1970s)	Russian combat-3 (Early 1980s)	Russian combat-4 (Mid 1990s)	Russian combat-5 (Early 2000s)
Stringers					
Al alloy	D16 AT	D19AT, D19AT	D19AT	D19A , B95, A4-1	
Ti alloy					OT4-1
Rib					
Al alloy	D16AT, AK4-1	D19AT, AK4-1	D19AT, AK4-1	D19Ch, AL9T4	B95, D19, 1420
Ti alloy				BT20	OT4-1
Spar					
Al alloy	B95, D16	D19, AK4-1, B93	D19, AK4-1, B93	D19Ch, AK4-1	D19Ch, AK4-1, B95
Steels	30KhGSA	30KhGSNA	30KhGSNA	30KhGSN2A	30KhGSN2A 30KhGSN2MA
Ti alloy				BT20	BT20
Landing Gear (strut and sleeve)					
Steel	30KhGSNA	30KhGSN2A	3-KhGSN2A	30KhGSN2A	30KhGSN2A

Titanium Alloys

Common titanium alloys used in Russian airframe structures are **Alpha Titanium alloys** OT4-1(Ti-2.0Al-1.5Mn) and BT5-1 (Ti-5Al-2.5Sn) and **Alpha plus beta alloys** BT 20(Ti-6.5Al-1.5V-1.5Mo) and BT 22 (Ti-4.5Al-4.5Mo-1Fe).

Use of Titanium alloys in Russian aircrafts of 60’s is very limited. But its application has increased progressively in later versions of Russian aircraft. In latest versions of aircraft of mid 90’s and early 2000’s, many of the load bearing structures are fabricated from Ti-alloy. Commonly used Ti alloy grades are OT4-1, BT5-1, BT20, BT22. Ti alloys are introduced as a viable replacement for steel because of high specific strength to weight ratio with comparable mechanical properties and improved corrosion resistance than that of steel. Ti alloys are better considered as a viable replacement for steels. It is seen from (Fig.1) that weight % of Ti alloys have been increased from nominal in Russian combat-1(mid 60’s) and 0.7% in Russian combat-2 and 3 (late 70’s and early 80’s) to 9% in Russian combat-4 (mid 90’s) and then to 13% (approximately) in Russian combat-5 (early 2000’s) aircraft which is shown later in this paper.

Magnesium Alloys

Magnesium is lightest engineering metal and its alloys are having strength between 15 to 28 kg/mm^2. However, there use in airframe remain restricted due to poor corrosion resistance, high notch sensitivity in fatigue and poor weldability. Principal Magnesium alloy grades used in airframe construction are MA8 (Mg-2Mn-Ce), MA14 (Mg-5.5Zn-Zr) and cast alloy ML-5 (Mg-8Al-Zn).

In 60’s Russian aircrafts, ML-5 was used for brake wheel applications. In later versions of aircraft, the wheels have been changed to Aluminium alloy AK6.

Copper and Copper Alloys

Copper and its alloys have limited use in aircraft construction. Various grades used are Brasses LS59-1 (Cu-40Zn-1Pb), L63 (Cu-37Zn), **Aluminium bronze** grades BRAZHMTs 10-3-1.5 (10Al-3Fe-1.5Mn), BRAZHN 10-4-4 (10Al-4Fe-4Ni) and **Beryllium bronze** BrB2 (2Be-Ni). Pure copper grade and brasses are mostly used in the electrical system and oxygen pipelines. Aluminium bronze finds application as bearing material such as bushes, rollers etc. Beryllium bronze is mostly used as spring materials and has replaced most of the steel spring material in latest aircrafts.

Table-2 : Mechanical properties of important structural materials of Russian Fighters

Grade of Material	Conditions	Yield Strength (*) (Kg/mm^2)	Ult. Tensile Strength (*) (Kg/mm^2)	% Elongation
30KhGSA	Hardened and Tempered	85	110	10
30KhGSNA	Hardened and Tempered	140	160	9
VNS 2	Hardened and Aged	-	125-140	10
VNS 5	Hardened and Aged	90	120	10
Kh18N9T	Hardened , Anneal	20	55	40
AE-703	Hardened	-	85	35
D16	Anneal		23	11
D16	Hardening and Natural age	27	41	10
D19	Anneal	-	24	10
D19	Hardening and Natural age	27	43	11
AK4-1	Hardening and Artificial age	32	42	6
AK4	Hardening and Artificial age	-	38	4
AK6	Hardening and Artificial age	28	39	10
AK8	Hardening and Artificial age	-	44	10
B93	Hardening and Artificial age	44	48	6
B95	Hardening and Artificial age	44	52	6
1420	Hardening and Artificial age	26-28	42	8
Brass LS59-1	Extruded and Drawn	-	40	12
Bronze 10-4-4	Extruded and Drawn	-	65	5
Bronze 10-3-1.5	Extruded and Drawn	-	60	12
OT4-1	Anneal	-	60-75	15-20
BT20	Anneal	-	93-108	10
(*) Values unless specified it is minimum				

Composite Material

Carbon Fibre Reinforced Plastic (CFRP) and Glass Fiber Reinforced Plastic (GFRP) are used to a limited extent. Applications of both CFRP and GFRP in Russian aircraft are shown at Table-1. Application of Honeycomb Sandwich structure has increased progressively till Russian aircrafts of mid 90's. However in latest version, use of Honeycomb has been reduced very significantly (3).

Evoluation of Skin Material

Skin material of Russian fighter aircraft has undergone significant changes over a period of time. It may be seen from Table-1 that in aircraft of 60's, all the skins at fuselage, wing, stabilizer and fins are made of cladded duralumin sheets of grade D16. Only over a small area at wing, grade B95 have been used. In later versions, the grade D16 has been fully replaced by a similar modified duralumin sheet grade D19. Stainless steel grade VNS2 is introduced as skin material in Russian combat-2 and 3 for the integral fuel cells, tank-2 and tank-4.

In subsequent aircraft combat versions, further change of skin material have been noticed. In mid 90's combat version, majority of skin is made from D19Ch and the rest are made from high strength Al-Zn alloy grade B95, Aluminium-lithium alloy grade 1420, Titanium alloys BT20 and OT4-1 have been introduced as skin material. The skin at tank-3 is from Stainless Steel grade VNS2 (ESR quality) and EP-817. Use of composite as skin is seen at a few places in this aircraft. In latest version of 2000's, grade D19 has been replaced by B95 in many of the areas of aircraft skin. In addition grades 1420, BT 20 and OT4-1 have been used considerably. Use of composite as a skin material is found to be insignificant in this aircraft due to introduction of Al-Li alloy.

Trend of Russian Aircraft Materials

Use of steel in aircraft construction is always under threat from its rival Aluminium and titanium alloys. Percentage uses of various alloys and composites in the construction of the airframe of these Russian aircraft is shown at Fig.1. It can be seen that there is considerable reduction in % weight of steel from 60's aircraft to the latest aircraft of 2000's. On the other hand weight % of Aluminium and Titanium alloys show increase in their usage as shown in Fig.1.

Conclusions

A study was carried for the first time to identify the airframe material section wise of all Russian military combat aircraft (Russian combat version 1 to 5) which are operated in Indian Air Force, by referring to available literature and failure/ operating experience of these aircraft. Comparison of these materials based on their characteristics and field performance and trend of material changes which was outlined in the study will bring awareness for User as well manufacturer of Russian fighters in usage of these aerospace materials during Rationalisation, Indigenisation, substitution and during short supply and non-availability of these grades.

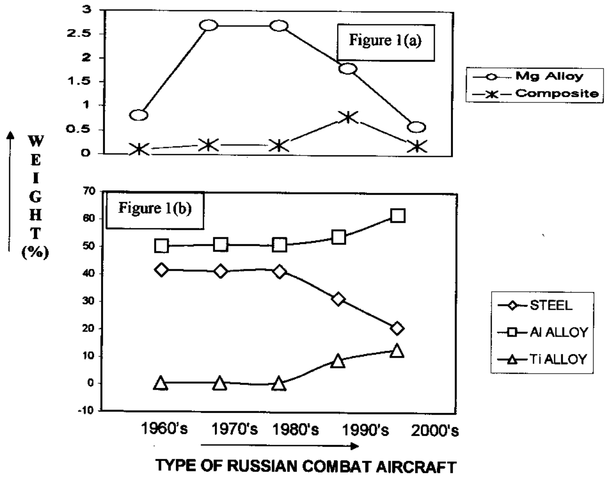

Fig. 1 Graph showing use of aircraft materials in weight % of Russian aircraft

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