TRANSMISSION, PTO and REDUCER BODIES

Gearboxes serve as powertrains. They can perform this power transmission function in line with the motion transmission of the gear wheels. Transmission parts that act as protectors for the safe performance of this process and against harmful elements that may come from external factors can be called transmission bodies.

It is preferable that the transmission bodies have strength-resistant, thermal-resistant, corrosion-resistant, shock-absorbing and oil-tight properties. In this regard, there are certain raw materials in the production of the transmission body.

Figure 1: KRD.28 Reducer body

Cast Iron

Cast iron, as a term, refers not only to a single material, but to a family of materials containing a significant amount of carbon and silicon, the main component of which is iron. The basic microstructural components of cast irons are the chemical and morphological forms formed by carbon and the continuous metal matrix in which carbon and/or carbide are dispersed. Cast irons contain microstructural components called graphite, carbide, ferrite, perlite, martensite, austenite and bainite. The presence of residual elements, the addition of alloy elements, the change in solidification behavior and the heat treatment applied after solidification enable the production of different types of cast iron with desired mechanical properties.

In the automotive industry, there are two types of cast iron materials commonly used in transmission and intermediate transmission bodies. These are;

1. Lamellar Graphite Cast Iron (GG)

It is a type of cast iron in which most of the carbon in its composition is in the form of free graphite sheets (lamellae) after solidification. Its surface has a sooty gray appearance when broken. This cast iron, which is brown in color due to graphite, is called lamellar graphite cast iron or GRAY CAST IRON.

The composition of gray cast iron includes carbon, silicon, manganese, phosphorus and sulfur, in addition to its main structure iron. These elements in its composition generally come from CRUDE IRON (pig). Sulfur is an undesirable element in gray cast iron. A small amount of phosphorus is useful.

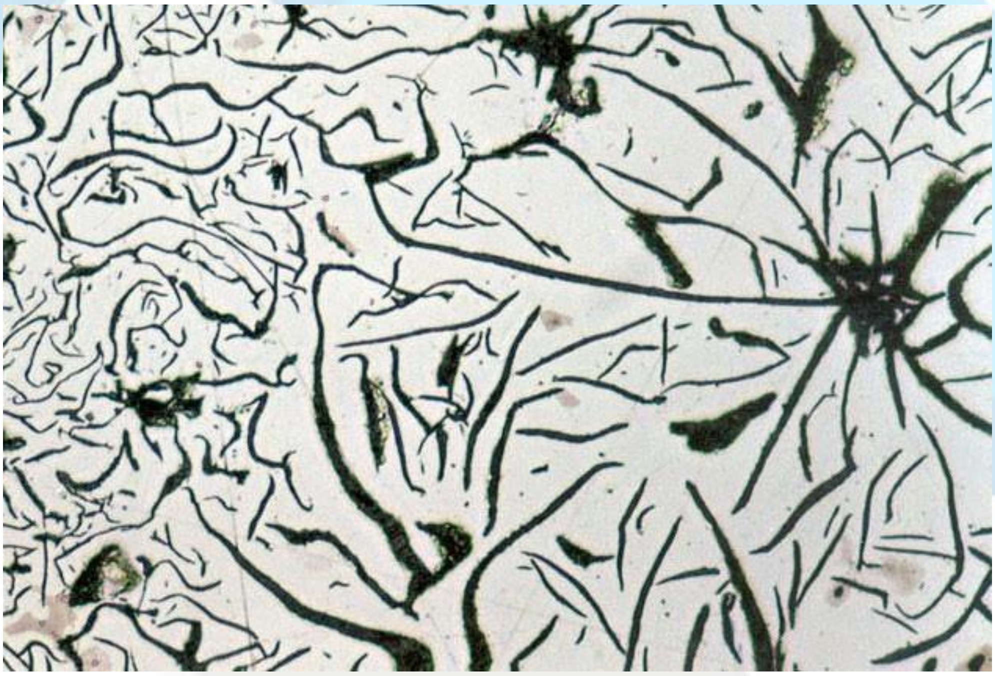

Figure 2: Microstructure of lamellar graphite cast iron material

Lamellar graphite cast irons are frequently used in the automotive industry. It is as good as steel in terms of heat treatment applicability and strength properties.

Lamellar graphite cast irons are also grouped according to their chemical components and physical properties.

	DIN	EN		
Grade	GG25	EN-GJL-250		
comparable with	Meehanite GD250			
Standard	DIN 1691	EN 1561		
Alloy number	0.6025	EN-JL 1040		
Chemical composition			Mechanical properties	
C	2,90 - 3,65			
Si	1,80 - 2,90		**Rm**	155 - 275
Mn	0,50 - 0,70		**HB**	160 - 250
S	0,10 max.			
P	0,30 max.			
kg/dm^3	ca. 7,2			

Characteristics GG25 is the most common flake cast iron grade. It offers a good combination of strength and wear resistance. It is recommended for uses where a balance is required between mechanical characteristics and machinability. Cast iron with flake graphite, predominant pearlitic structure. Heat treatment is not recommended.

	DIN	EN		
Grade	GG30	EN-GJL-300		
comparable with	Meehanite GB300			
Standard	DIN 1691	EN 1561		
Alloy number	0.6030	EN-JL 1050		
Chemical composition			Mechanical properties	
C	2,90 - 3,65			
Si	1,80 - 2,90		**Rm**	170 - 325
Mn	0,10 - 0,30		**HB**	190 - 260
S	0,10 max.			
P	0,30 max.			
kg/dm^3	ca. 7,2			

Charactristics Offers a higher wear resistance, strength and heat treatment response compared to GG20 and GG25 while still possessing reasonable machinability and excellent surface finish. GG30 can be hardened by conventional methods to Rc 50 on the bar surface.

	DIN	EN		
Grade	GG35	EN-GJL-350		
comparable with	Meehanite GA350			
Standard	DIN 1691	EN 1561		
Alloy number	0.6035	EN-JL 1060		
Chemical composition			Mechanical properties	
C	2,90 - 3,65			
Si	1,80 - 2,90		**Rm**	210 - 375
Mn	0,50 - 0,70		**HB**	240 - 300
S	0,10 max.			
P	0,30 max.			
kg/dm^3	ca. 7,2			

Characteristics GG35 is an excellent wear resistance cast iron grade while still possessing reasonable machinability characteristics. GG35 can be hardened by conventional methods to Rc 50 on the bar surface.

Figure 3: Comparison of lamellar graphite cast irons

As can be seen in Figure 3, there are different types of cast iron with lamella graphite. Lamellar graphite cast irons are named with coding system such as GG25, GG30, etc. Here, the 'GG' part in GG25 indicates that it is lamellar graphite cast iron, while the '25' part indicates that it is resistant to a tensile strength of 250 Mpa. It is observed that the corrosion and surface resistance properties improve as the numerical value increases. However, the cost also increases accordingly.

2. Spheroidal Graphite Cast Iron (GGG)

Spheroidal graphite cast iron is cast iron in which the graphite in its composition has a spherical shape. This cast iron is also called DUCTILE IRON. A small amount of Magnesium (Mg) or Cerium (Ce) is added to the molten cast iron to allow the carbon to change from a leafy lamella to a spherical shape. The shape of graphite sheets in gray cast irons is the main factor that reduces the strength, toughness and ductility of gray cast iron due to its cracking properties. This specially obtained cast iron is called spheroidal graphite cast iron due to its graphite structure.

Spheroidal graphite cast iron is used in various applications as a substitute for gray cast iron, cast steel and non-ferrous metal alloys. Spheroidal graphite cast irons are known as "nodular cast iron, ductile iron, fonte spheroidal graphite, kufelgrapfit gusseisen, spheregus" in many countries. Its name in Turkish standards is SPHEROIDAL GRAPHITE CAST IRON. Its abbreviation is "GGG". In another approach, Spheroidal graphite cast irons can be described as a more advanced form of lamellar graphite cast irons.

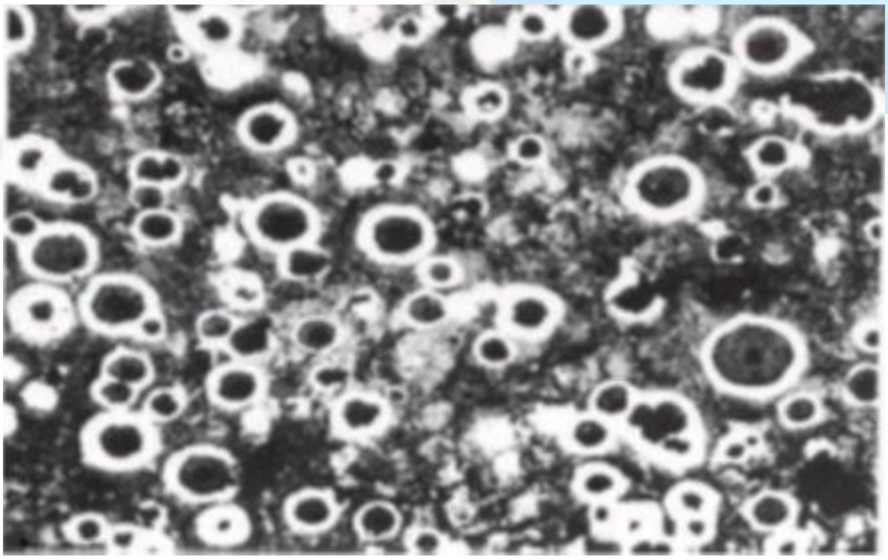

Figure 4: Microstructure of spheroidal graphite cast iron material

Spheroidal graphite cast irons can be used in applications where lamellar graphite cast irons may be insufficient. Especially in terms of strength, they are superior to lamellar graphite cast irons. Spheroidal graphite cast irons are divided into groups within each other, just like lamellar graphites.

Grade	GGG40	EN-GJS-400-15		
comparable with	Meehanite SF400			
Standard	DIN 1693	EN 1563		
Alloy number	0.7040	EN-JS 1030		
Chemical composition			Mechanical properties	
C	3,40 - 3,85			
Si	2,30 - 3,10		**Rm**	400
Mn	0,10 - 0,30		**Rp 0,2**	250
S	0,02 max.		**A5**	15
P	0,10 max.		**HB**	130-180
kg/dm^3	ca. 7,2			
Characteristics	GGG40 is the most common used nodular cast iron. Nodular cast iron has predominately a ferritic structure. Offers superior machinability combined with optimal impact, fatigue, electrical conductivity and magnetic permeability. Fur use beneath 0°C a special grade (GGG40.3 or EN-GJC400-18-LT) can be produced with a very high inpacttest value.			

	DIN	**EN**		
Grade	GGG50	EN-GJS-500-7		
comparable with	Meehanite SFP500			
Standard	DIN 1693	EN 1563		
Alloy number	0.7050	EN-JS 1050		
Chemical composition			Mechanical properties	
C	3,40 - 3,85			
Si	2,30 - 3,10		**Rm**	500
Mn	0,10 - 0,30		**Rp 0,2**	320
S	0,02 max.		**A5**	7
P	0,10 max.		**HB**	170-240
kg/dm^3	ca. 7,2			
Characteristics	Has a ferritic /pearlitic structure. Offers higher wear resistance, strength and heat treatment response compared with GGG40 while still possessing reasonable machinability and excellent surface finishing.			

	DIN	**EN**		
Grade	GGG60	EN-GJS-600-3		
comparable with	Meehanite SP600			
Standard	DIN 1693	EN 1563		
Alloy number	0.7060	EN-JS 1060		
Chemical composition			Mechanical properties	
C	3,40 - 3,85			
Si	2,30 - 3,10		**Rm**	600
Mn	0,10 - 0,30		**Rp 0,2**	360
S	0,02 max.		**A5**	3
P	0,10 max.		**HB**	200-260
kg/dm^3	ca. 7,2			
Characteristics	Has a predominately pearlitic structure. Very good machinability combined with higher wear resistance, strength and less elongation than GGG50.			

	DIN	**EN**		
Grade	GGG70	EN-GJS-700-2		
comparable with	Meehanite SP700			
Standard	DIN 1693	EN 1563		
Alloy number	0.7070	EN-JS 1070		
Chemical composition			Mechanical properties	
C	3,40 - 3,85			
Si	2,30 - 3,10		**Rm**	700
Mn	0,10 - 0,30		**Rp 0,2**	400
S	0,02 max.		**A5**	2
P	0,10 max.		**HB**	240-300
kg/dm^3	ca. 7,2			
Characteristics	Pearlitic structure with higher mechanical values than GGG50 and GGG60 with an even better wear resistance. Despite the high hardness still reasonable machinability and excellent surface finish.			

Figure 5: Comparison of spheroidal graphite cast irons

As can be seen in Figure 5, there are different types of spheroidal graphite cast iron varieties. Spheroidal graphite cast irons are named with coding system such as GGG40, GGG50, etc. Here, the ‘GGG’ part in GGG40 indicates that it is spheroidal graphite cast iron, while the ‘40’ part indicates that it is resistant to a tensile strength of 400 Mpa. It is observed that the corrosion and surface resistance properties improve as the numerical value increases. However, the cost also increases accordingly.

In line with the properties given, it is seen that spheroidal graphite cast irons are more durable than lamellar graphite cast irons.

Table 1. **Properties in cast-on test pieces**

Grade according to DIN 1693 Part 1: Symbol	Grade according to DIN 1693 Part 1: Material number	Ruling wall thickness of the casting (mm)	Thickness of cast-on test piece (mm)	Tensile strength R_m (N/mm² min.)	0.2 % yield limit $R_{p\,0,2}$ 1) (N/mm² min.)	Elongation at break A_5 (% min.)	Absorbed energy 2) (DVM specimens) at – 20 °C A: average of 3 specimens (Joule min.)	Absorbed energy: individual value (Joule min.)	Reference data: Structure
GGG-40.3	0.7043	from 30 to 60 over 60 to 200	40 70	390 370	250 240	15 12	14 12	11 9	predominantly ferritic
GGG-40	0.7040	from 30 to 60 over 60 to 200	40 70	390 370	250 240	15 12	–		predominantly ferritic
GGG-50	0.7050	from 30 to 60 over 60 to 200	40 70	450 420	300 290	7 5	–		ferritic/ pearlitic
GGG-60 3)	0.7060	from 30 to 60 over 60 to 200	40 70	600 550	360 340	2 1	–		pearlitic/ ferritic
GGG-70 3)	0.7070	from 30 to 60 over 60 to 200	40 70	700 650	400 380	2 1	–		predominantly pearlitic

1) Instead of the 0.2 % yield limit it is permissible in the case of the ferritic grade to quote the yield point obtained from the testing machine diagram, due regard being paid to the more restricted process conditions compared with DIN 50 145, as referred to in the Explanations.

2) For other test temperatures the values for absorbed energy are to be agreed.

3) Tensile strength and elongation are not guaranteed if minimum hardness values are specified for reasons of increased wear resistance.

Figure 6: Another approach to comparison of spheroidal graphite cast irons

Elements that Increase the Corrosion Resistance of Cast Irons

Corrosion is one of the most common types of problems encountered in metals. There are factors that increase corrosion resistance in the industry.

Chromium (Cr): In order to increase corrosion resistance and oxidation resistance, chromium can be added provided it does not exceed 35%.

Nickel (Ni): It has been found to increase corrosion resistance properties when used with Cr. Alloys containing 14% Ni and 1.5% Cr may be resistant to corrosion.

Silicon (Si): Silicon forms a protective SiO_2 layer on the surface, as it increases the passivation property of iron. This layer has protective properties against corrosion. A rate of 14% is recommended for Si.

Copper (Cu): Copper can also be used as an anti-corrosion agent, however, it is not preferred much due to its negative properties.

Aluminum Alloys

The first reason for using aluminum alloys is to reduce the weight of the transmission in the vehicle. However, its main disadvantage is that it is costly compared to gray cast iron. Aluminum alloys have better machinability properties compared to grey cast iron.

Another advantage of aluminum alloys is that their thermal conductivity is much higher compared to gray cast irons. This also prevents the internal components of the transmission from overheating.

In the selection of aluminum material for the transmission body, alloys differ from each other. These are;

ETINORM	ETIAL-110	ETIAL-120	ETIAL-140	ETIAL-141	ETIAL-145	ETIAL-147	ETIAL-150	ETIAL-160
SPECIFIC GRAVITY (gr/cm^3)	2,76	2,68	2,66	2,66	2,69	2,76	2,67	2,76
MELTING RANGE (ºC)	525-625	575-630	575-585	575-585	535-590	520-580	525-580	540-595
HEAT CONDUCTIVITY (cal/cm.sºC)	0,32	0,35	0,37	0,29	0,21	0,25	-	0,23
CORROSION RESISTANCE	MODERATE	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	MODERATE	MODERATE	MODERATE
CASTABILITY	VERY GOOD	EXCELLENT	EXCELLENT	EXCELLENT	GOOD	GOOD	EXCELLENT	GOOD
MACHINABILITY	GOOD	MODERATE	MODERATE	MODERATE	GOOD	GOOD	GOOD	GOOD
ANODIC OXIDATION	Only on Surface Protection							
OTHER PROPERTIES AND PLACES OF USE	Good Casting, Weldability Characteristic, Cylinder heads, crank covers of combustion engines.	Kitchenware, food handling equipment, marine fittings, various thin section castings.	Thin section and mixed castings, engine boxes, measurement boxes, pump parts, marine atmosphere.	Mixed and thin walled pressurized castings.	Sand and mold castings, Castings, pistons and other engine parts	Mold castings, iron base.	Used in high-strength pressurized castings.	Used in pressurized casting parts requiring good surfaces.

Figure 7: Physical and chemical properties of aluminum alloys

ETINORM	ETIAL-171	ETIAL-175	ETIAL-177	ETIAL-180	ETIAL-195	ETIAL-220	ETIAL-221	ETIAL-509
SPECIFIC GRAVITY (gr/cm^3)	2,64	2,76	2,68	2,74	-	-	2,77	2,6
MELTING RANGE (ºC)	575-595	520-580	-	570-525	-	-	541-647	520-620
HEAT CONDUCTIVITY (cal/cm.sºC)	0,27	0,25	0,38	0,24	-	-	0,35	0,24
CORROSION RESISTANCE	VERY GOOD	MODERATE	GOOD	GOOD	GOOD	BAD	BAD	EXCELLENT
CASTABILITY	EXCELLENT	GOOD	GOOD	GOOD	GOOD	BAD	BAD	GOOD
MACHINABILITY	MODERATE	GOOD	MODERATE	GOOD	GOOD	VERY GOOD	VERY GOOD	VERY GOOD
ANODIC OXIDATION	Only on Surface Protection							
OTHER PROPERTIES AND PLACES OF USE	Strength casting properties, corrosion resistance, pressure sealing.	Resistant to hot crack, has very good fluidity. Used in pistons of internal combustion engines.	Used in pressurized seal rim production in automotive industry.	A general purpose alloy with a wide area of used. Used in pressurized castings.	Used in piston production and cylinder blocks of internal combustion engines.	Used in sand and mold castings and gearboxes.	Used in sand and mold castings, general engineering applications, airplanes.	Corrosion resistant casting kitchen and office machinery bodies, optical tools, decorative casting parts and press castings.

Figure 8: Physical and chemical properties of aluminum alloys (cont.)

Elements that Increase the Corrosion Resistance of Aluminum Alloys

As with cast irons, there are also elements that increase corrosion resistance of aluminum alloys. The difference of the construction material and the characteristic of the element added to the alloy are not always the same. For example, while chromium (Cr) has corrosion resistance enhancing properties in cast irons, the same cannot be observed in aluminum alloys.

	Fe	Si	Mg	Mn	Cu	Zn	Ti	Cr	Ni	Li	Zr	V	Sn	B	Bi	Pb
Density	↑	↓	↓	↑	↑	↑	↑	↑	↑	↓	↑	↑	↑	↓	↑	↑
Fluidity	↓	↑	↑	↓	↓	~	↓	-	-	-	-	-	-	-	-	-
Hardening	↑	↑	↑	↑↑	↑↑↑	↑↑↑	↑	↑	-	-	-	-	↓	-	-	↓
Resistance Frictional Res.*	↑	↑	↑	↑	* ↑↑	↑↑↑	↑↑	-	* ↑	-	-	-	* ↑	↑	-	-
Electrical Cond.	↓	↓↓	↓↓	↓↓↓	↓↓	↓	↓↓↓	↓↓↓	↓	↓↓↓	↓↓	↓↓	-	↑↑↑	-	-
Corrosion Strength	-	↑	↑↑↑	↑↑	↓	↓	-	-	↓	-	-	-	↓	-	↓	↓
Thermal Expansion Factor	-	↓	↓	↓	↓	↑	↓	↓	↓	-	↓	↓	-	-	-	-

Remarks:

↑ Increase

↓ Decrease

~ Does not change

\- Uncharacteristic or unknown

Multiple arrows: Stronger impact

Figure 9: Contributions of the elements added to the aluminum alloy to the physical property

As seen in Figure 9, the elements Magnesium (Mg), Manganese (Mn) and Silicon (Si) have properties that increase corrosion resistance. However, there are some parameters to be considered when using these elements. For example, the element Silicon (Si), which is used to prevent corrosion, can also change other properties, and this may not always be desirable. Magnesium (Mg) is the most commonly used anti-corrosion element in aluminum alloys.

Aluminum Alloys with Magnesium

Aluminum has been used in transmissions and intermediate transmissions for about 50 years due to its resistance to high temperatures and its ability to endure mechanical stresses. Today, it has begun to replace cast iron. However, the aluminum body is 66% lighter than ones made of cast iron, while the magnesium alloy body is 75% lighter. In addition to being lighter, magnesium has high shock and collapse resistance. It also absorbs sound and vibration better than aluminum. This decrease in weight results in a decrease in fuel consumption and exhaust emissions.

The advantages of magnesium and magnesium alloys are as follows;

- It is the one with the lowest density among all metallic structural elements (1738 kg/^{3}).
- It provides high specific strength.
- It has good pourability and is suitable for high-pressure mold castings.
- It can be turned and milled at high speeds.
- It can be well welded under controlled atmospheric conditions.

Different Transmission and Intermediate Transmission Manufacturers

In line with the researches carried out, the material use of different transmission and intermediate transmission manufacturers may vary under different conditions. The material used by a manufacturer is given below as an example.

Bevel gearboxes BG Series

Materials and components

Housing
- cubic shape
- material: grey cast iron EN-GJL-250 (UNI EN 1561)
- all 6 sides machine finished
- on request: stainless steel

Covers and hubs
- material: grey cast iron EN-GJL-250 (UNI EN 1561)
- machining: internal centring tolerance **h7**, outer centring tolerance **f7**
- on request: stainless steel

Solid shafts
- material: carbon steel C45E +H +QT (UNI EN 10083-2), hardened and tempered
- machining: cylindrical end, ground in tolerance **j6**, with key according to DIN 6885 Part 1
- on request: stainless steel
  shaft end with spline profile according to DIN 5480
  shaft end machined to drawing

Hollow shafts
- material: input hollow shaft - carbon steel C45E +H +QT (UNI EN 10083-2), hardened and tempered
  output hollow shaft - alloy steel 39 NiCrMo 3 (UNI EN 10083-3), hardened and tempered
- machining: cylindrical end, ground in tolerance **H7**, with keyway according to DIN 6885 Part 1
- on request: stainless steel
  bore with spline profile according to ISO 14

Bevel gears
- material: alloy steel 20 MnCr 5 (UNI EN 10084), case-hardened and tempered
- toothing: GLEASON, with spiroidal tooth
- running in with lapping in pairs

Seals
- oil seals in NBR, on request in VITON
- O-rings in NBR

Bearings
- taper roller bearings on solid output shaft and input shafts
- ball bearings on hollow input shaft for motor flange
- on request: larger bearings for higher radial and/or axial load capacity

Figure 10: Materials used in BG bevel transmission of Servomech company

CONCLUSION

In the automotive industry, a wide range of transmission and intermediate transmission body materials can be preferred. Determining certain priorities plays an important role in making this choice. For example, while aluminum alloys stand out in terms of lightness and heat permeability, cast iron materials seem to be more advantageous in terms of strength and cost.

The GGG50 cast iron material used in our company is relatively high quality, however, there are cast iron materials that are more resistant to corrosion. The most important thing to consider in this regard is to determine whether the correct proportion of alloying elements is used in this GGG50 material cast by the supplier. At the same time, in line with the process of spherification of graphites, there are a number of different metal elements that need to be added in the molten state of the lamellar graphite phase cast material. It is necessary to strictly control how accurately these issues can be done by the supplier company. Likewise, ETIAL-171 material used as aluminum alloy can be considered good also. While better anti-corrosion aluminum alloys are available, cost calculation is an important issue that should not be overlooked when choosing materials.

As shown in Figure 10, Servomech company used EN-GJL-250 as the body material, that is, the lamellar graphite cast iron material GG25 mentioned in the report. Although the selection of GG25 material, which is relatively poor quality, is an issue to be considered, the selection of 20MnCr5 as a gear material is also a factor that should not be overlooked in the material selection of the gears designed by us. Because while this other company is willing to compromise on the quality of the body material, it has definitely not compromised on the gear material.