PRACTICAL RUBBER COMPOUNDING AND PROCESSING

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PREFACE

An attempt has been made in this book to simplify the many facets of rubber compounding and processing plant in use throughout the world. The emphasis throughout is of a practical nature and on problems encountered in the day-to-day running of a typical rubber factory.

Scientific explanations and descriptions have, however, been included, but only where essential for understanding; no attempt has been made to enter into wider theoretical aspects. There are already many excellent works in this field, and these should be referred to if further information is required. In addition, all the major chemical and rubber suppliers to the industry will be only too pleased to assist if requested.

I would like to thank my company and colleagues for their help and advice, and also my secretaries Mrs Helen Fielding and Mrs Leslie Maddison for their invaluable assistance; also the plant and machinery manufacturers who have supplied photographs (acknowledgement is made in the text). Gratitude is also expressed to my many friends within the ISO, BSI, and the British and American Rubber Manufacturers Associations. In addition, I am also grateful to them for permission to use information.

In conclusion, I would especially thank my wife for her usual encouragement, good humour and understanding, during the long months of the book's preparation.

COLIN W. EVANS
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CHAPTER 1

POLYMERS AND RAW MATERIALS

Rubber compounding as we know it today is the result of the considerable work, effort, and contributions of countless workers in this field, since the discovery of vulcanisation in 1839. It covers almost a century and a half of applied research and development, and the healthy state of this science and the rubber industry today, is in no small measure due to this.

Today's compounder or rubber chemist must be competent in the use and application of both natural and synthetic materials, and, to do this to best advantage, requires the following:

(1) An understanding of the plant and processing methods available.
(2) A thorough knowledge of both the chemical and physical properties of the raw materials available.
(3) A knowledge of these materials and their modifications contributing to satisfactory service life of the compound and the final product.
(4) A knowledge of the vulcanising systems available in order to bring out, develop and maximise the ultimate properties of the materials used.
(5) An understanding of the in-process and final testing of the finished products, so as to ensure consistency.
(6) Last, but by no means least, the capability of producing material that will process well in the factory, and at the right price to be commercially viable.

The polymers and elastomers listed in Table 1 are widely used in everyday and specialised rubber goods manufacture. For ease and convenience they are shown also with their general properties and characteristics.

TABLE 1

POLYMERS AND ELASTOMERS USED IN RUBBER MANUFACTURE

International designation	*Common name*	*Chemical composition*	*General properties*
ABR	Acrylic	Acrylate–Butadiene	Excellent high temperature oil and air. Poor cold flow and low temperature. Not recommended for water service.
AFMU	Fluon Teflon PTFE	Tetrafluoroethylene	Excellent and outstanding high temperature and chemical resistance.
AU	Urethane	Polyester	Excellent ageing, abrasion, tear and solvent resisting properties. Poor high temperature characteristics.
BIIR	Brominated butyl	Bromo-isobutene–Isoprene	Excellent ageing, and weathering resistance with good physical properties. Low permeability to air. Very poor resistance to petroleum based fluids.
BR	Butadiene rubber	Butadiene	Excellent low temperature and abrasion properties, with high resilience.
CIIR	Chlorinated butyl	Chloro-isobutene–Isoprene	As for BIIR.
CM	Chlorinated Polyethylene	Chloropolyethylene	Excellent UV, weathering, oil, chemical and flame resistance. Good low temperature impact resistance.

CO	Hydrin	Polychloromethyl oxirane	Excellent ozone and oil resistance, with low permeability to gases. Good flame resistance, with moderate low temperature properties.
CR	Neoprene	Chloroprene	Good ageing and weathering resistance with good physical properties. Fair resistance to petroleum based fluids, but not high aromatics. Flame retarding.
CSM	Hypalon	Chlorosulphonyl-polyethylene	Excellent weathering, ozone, and acid resistance. Reasonable resistance to petroleum based fluids but not aromatics.
ECO	Hydrin	Ethylene oxide and chloromethyl oxirane	Excellent ozone and oil resistance. Good low temperature properties. Reasonable flame resistance; with low gas permeability.
EPDM	Ethylene propylene rubber	Ethylene propylene diene terpolymer	Excellent resistance to weathering, ozone, heat, water, steam, glycolether brake fluids and vegetable oils. Poor resistance to petroleum based fluids, including mineral oils.
EPM	Ethylene propylene rubber	Ethylene propylene	
EPR	Ethylene propylene rubber	Ethylene propylene	

(continued)

TABLE 1—*contd.*

International designation	*Common name*	*Chemical composition*	*General properties*
EPT	Ethylene propylene rubber	Ethylene propylene terpolymer	
EU	Urethane	Polyether	Excellent ageing, abrasion, tear and solvent resisting properties. Poor high temperature characteristics.
FMQ	Fluorosilicone	Trifluoropropyl siloxane	Excellent mineral oil fuel resistance. Other properties as VMQ.
FPM	Viton fluorocarbon	Hexafluoropropylene·vinylidene fluoride	Excellent high temperature resistance with air and oil. Excellent chemical resistance.
IR	Polyisoprene	Isoprene, synthetic	As for natural rubber.
IIR	Butyl	Iso-butene isoprene	As for BIIR.
NR	Natural	Isoprene, natural	Excellent physical properties including abrasion, and low temperature resistance. Poor resistance to petroleum based fluids.
NBR	Nitrile Buna N	Nitrile butadiene	Excellent resistance to petroleum based fluids with good physical properties. Reasonably resistant to aromatics.
PA	Nylon	Polyamide	Good abrasion, chemical, high temperature and fatigue resistance. Low gas permeation, and a very low coefficient of friction.

PE	Polythene Polyethylene	Ethylene	Excellent dielectric, water, acid, alkali and chemical resistance.
PP	Polypropylene	Propylene	
PTFE	See AFMU		
PVC	Polyvinyl chloride	Vinyl chloride	Good weather resistance, flame resistance. Poor low and high temperature properties.
SBR	SBR (Originally known as GRS)	Styrene–Butadiene	Good physical properties, including abrasion, but has poor resistance to petroleum based fluids.
T	Thiokol	Organic polysulphide	Exceptional solvent and weather resistance. Most other properties, poor.
—	Thermoplastic rubber	Polyolefins Blocked co-polymers of styrene and butadiene	Good weather and chemical resistance between −50 °C and +120 °C.
VMQ	Silicone	Dimethyl polysiloxane	Excellent high and low temperature resistance, with reasonable physical properties.
XPLE	Cross-linked polyethylene	Polyethylene with cross-linking agent	Excellent chemical, heat and electrical properties.

CARBON BLACK

Perhaps at first glance, the lists of the various carbon blacks available to the rubber compounder is rather confusing and frightening. It could even be argued that there are far too many types available, and that some rationalisation is long overdue. The carbon black producers would be the first to agree with this, and indeed attempts are currently being made in this direction by them. Unfortunately, in the past, to give the industry and the user what industry *believes* it requires, the carbon black producers have been over co-operative. Subsequently, because of this the present proliferation has occurred.

However, the following historical background into the available types of carbon black will be of interest (Courtesy: Cabot Carbon and Ashland Chemicals) and it is trusted will help clarify the situation somewhat.

Classification of Carbon Blacks

The former 'industry letter' classification system of carbon black grades for rubber, which is still used, is confusing and even ludicrous. As each new grade was introduced, its sponsor gave it a designation different from prevailing grades and descriptive of its distinguishing characteristics. Thus, we have classification in accordance with levels of abrasion resistance—high abrasion furnace (HAF), intermediate super abrasion furnace (ISAF), and super abrasion furnace (SAF); classification in accordance to reinforcement—semi-reinforcing furnace (SRF); classification based on vulcanisate property—high modulus furnace (HMF); classification based on a rubber processing property—fast extrusion furnace (FEF); classification based on usefulness—general purpose furnace (GPF) and all-purpose (APF); classification based on 'particle' size—fine furnace (FF), and large particle size furnace (LPF); and a classification based on electrical conductive properties (XCF). Within some of these broad grades there are a variety of subgrades having different 'structure' levels, an example being HAP, with a high structure subgrade (HAF-HS) and a low structure subgrade (HAF-LS). Other features have been used to designate various subgrades. The obvious inadequacies of this unwieldy classification procedure led the ASTM Committee D-24 on carbon black to establish a letter and number system, illustrated in Table 2. In the ASTM system the N-series numbers increase as iodine adsorption values or surface areas decrease. The SAF grades have designated numbers from N100–N199; the ISAF grades, N200–

TABLE 2
CARBON BLACK—ASTM GRADE NUMBERS

Blacks	*Iodine adsorption range*
N1	140 maximum
N2	100–139
N3	75–99
N4	55–74
N5	41–54
N6	32–40
N7	20–31
N8	15–19
N9	Below 15

N299; the HAF grades, N300–N399; the HMF, GPF, and APF grades, N600–N699; the SRF grades, N700–N799; fine thermal (FT) has been designated as N880, and medium thermal (MT) N990. Quality variations, such as differences in structure, are given arbitrary numbers within a grade. Table 3 lists a selected group of carbon black grades, their ASTM number, their type category and some important typical analytical properties.

A first glance at Table 3 leads one to question the need for so many ASTM grade numbers, some of them being rather close in distinguishing properties. The answer is that iodine adsorption and DBP do not in themselves classify adequately carbon black performance. Thus, improvements or changes in process technology may provide a product with similar values of iodine adsorption and DBP value to an existing grade but with performance features different enough to require a new number. The finest particle size grade is designated by the N100 series of numbers and the numbers increase with increasing 'particle' size or decreasing surface area to the largest particle size grades which are the N900 series. A new grade may be introduced to fill a gap in the quality range, to satisfy a customer need or to provide a lower cost product. It is obvious that these discrete particles have resulted in such a proliferation of grades that rubber compounders find them difficult to understand and expensive to evaluate and stock. Also, the larger number of grades increases manufacturing, storage and distribution costs. In recent years there has been an effort on the part of both suppliers and customers to rationalise the carbon black grade dilemma. It will be seen that as well as black numbers being in an N-series, there are a few blacks with the prefix 'S'. The prefix 'N' stands for normal cure and 'S'

TABLE 3

TYPICAL ANALYTICAL PROPERTIES OF RUBBER GRADE CARBON BLACKS

Nomenclature ASTM[a]	*Type*	*Typical iodine adsorption Number D1510*[b]	*Typical DBP Number D2414*	*Typical pour density, kg/m³ (lb/ft³) D1513*	*Tinting strength*[c] *IRB no. 3 (%)*
N110	SAF	145	113	335 (21·0)	128
N121	SAF–HS	120	130	320 (20·0)	
N166		150	135	320 (20·0)	122
S212		117	86	400 (25·0)	—
N219	ISAF–LS	118	78	440 (27·5)	124
N220	ISAF	121	114	345 (21·5)	114
N231	ISAF–LM	125	91	390 (24·5)	117
N234		118	125	320 (20·0)	130
N242	ISAF–HS	123	126	330 (20·5)	119
N270		102	124	345 (21·5)	—
N285		102	126	335 (21·0)	104
N293	CF	145	100	375 (23·5)	119
N294	SCF	205	106	370 (23·0)	119
S300		105	102	350 (22·0)	—
S301		115	99	350 (22·0)	—
S315		86	79	450 (28·0)	—
N326	HAF–LS	82	71	465 (29·0)	109
N327		86	60	510 (32·0)	120
N330	HAF	82	102	375 (23·5)	104
N332		84	102	375 (23·5)	118
N339	HAF–HS	90	120	345 (21·5)	114
N347	HAF–HS	90	124	335 (21·0)	104
N351		67	120	345 (21·5)	100
N356		93	150	305 (19·0)	103
N358	SPF	84	150	290 (18·0)	99
N363		66	68	480 (30·0)	110
N375	HAF	90	114	360 (22·5)	116
N440	FF	50	60	480 (30·0)	—
N472	XCF	270	178	255 (16·0)	
N539		42	109	385 (24·0)	—
N542		44	67	505 (31·5)	
N550	FEF	43	121	360 (22·5)	—
N568	FEF–HS	45	132	335 (21·0)	—
N601		35	84	425 (26·5)	—
N650	GPF–HS	36	125	370 (23)	—
N660	GPF	36	91	425 (26·5)	—
N683	APF	30	132	335 (21·0)	—
N741		20	105	370 (23·0)	—
N754		25	58	495 (31·0)	—
N762	SRF–LM	26	62	505 (31·5)	—
N765	SRF–HS	31	111	375 (23·5)	—
N774	SRF–HM	27	70	495 (31·0)	—

TABLE 3—*contd.*

Nomenclature ASTM[a]	*Type*	*Typical iodine adsorption Number D1510*[b]	*Typical DBP Number D2414*	*Typical pour density, kg/m³ (lb/ft³) D1513*	*Tinting strength*[c] *IRB no. 3 (%)*
N785		25	126	335 (21·0)	—
N787		31	81	450 (28·0)	—
N880	FT	13	35	605 (38·0)	—
N881	FT	13	35	605 (38·0)	—
N907	MT	7	33	655 (41·0)	—
N908	MT	7	33	655 (41·0)	—
N990	MT	7	33	655 (41·0)	—
N991	MT	7	33	655 (41·0)	—

[a] ASTM designations are determined according to Recommended Practice D2516, Nomenclature for Rubber-Grade Carbon Blacks.
[b] In general, Method D1510 can be used to estimate the surface area of furnace blacks but not channel, oxidised, or thermal blacks.
[c] Industry reference HAF black taken as 100.

indicates a slow curing black. At one time, the slow blacks were chemical blacks, but these are no longer available and any 'S' black is now an oxidised furnace one. In the 'N' series the numbers increase as iodine adsorption values decrease, but no range of values are as yet specified. This is under very active consideration within the carbon black committee of ISO TC45 and will very shortly be specified. The suggested ranges are shown in Table 2.

Properties of Carbon Black/Rubber Compounds

The general effects of carbon black on rubber properties are similar in all rubbers, being dominated mainly by surface area, 'particle' size and 'structure' level or aggregate size. High surface area, small 'particle' size carbon blacks impart higher levels of reinforcement as reflected in tensile strength and resistance to abrasion and tearing. Higher hysteresis and poorer dynamic performance are the price paid for these improvements. Higher 'structure' or aggregate size gives improved extrusion behaviour, higher stock viscosities, improved 'green' strength and higher modulus values. A summary of the effects of carbon black 'structure' and 'particle' size on rubber processing and vulcanisate properties is listed in Table 4.

TABLE 4

APPLICATIONS OF MAJOR RUBBER GRADE CARBON BLACKS

ASTM N-Type	*Designation*	*General rubber properties*	*Typical uses*
N990	Medium thermal (MT)	Low reinforcement, modulus, hardness, hysteresis, tensile strength; high loading capacity and high elongation	Wire insulation and jackets, mechanical goods, footwear, belts, hose, packings, gaskets, O-rings, mountings, tyre innerliners
N880	Fine thermal (FT)	Low reinforcement, modulus, hardness, hysteresis, tensile strength; high elongation, tear strength, and flex resistance	Mechanical goods, gloves, bladders, tubes, footwear uppers
N700 Series	Semi-reinforcing (SRF)	Medium reinforcement, high elongation, high resilience, low compression set	Mechanical goods, footwear, inner tubes, floor mats, hose
N660	General purpose (GPF)	Medium reinforcement, medium modulus, good flex and fatigue resistance, low heat build-up	Standard tyre carcass black; tyre innerliners and widewalls; sealing rings, cable jackets, hose, soling, and extruded goods; EPDM compounds
N650	General purpose-high structure (GPF–HS)	Medium reinforcement, high modulus and hardness, low die swell, smooth extrusion	Tyre innerliners, carcass, radial belt and sidewall compounds; extruded goods and hose
N550	Fast extrusion (FEF)	Medium-high reinforcement; high modulus and hardness; low die swell and smooth extrusion	Tyre innerliners, carcass, and sidewall compounds; innertubes, hose and extruded goods
N326	High abrasion-low structure (HAF–LS)	Medium-high reinforcement; low modulus, high elongation, good fatigue resistance, flex resistance, and tear strength	Tyre belt, carcass, and sidewall compounds
N330	High abrasion (HAF)	Medium-high reinforcement; moderate modulus, good processing	Tyre belt, sidewall, and carcass compounds; retread compounds, mechanical and extruded goods
N339, N347, N375	High abrasion-high structure (HAF–HS)	High reinforcement, modulus, and hardness; excellent processing	Standard tyre tread blacks
N220	Intermediate super abrasion (ISAF)	High reinforcement, tear resistance; good processing	Passenger and off-the-road tyre treads; special service tyres
N110	Super abrasion (SAF)	High reinforcement	Special tyre treads, airplane, off-the-road, racing tyres; products for highly abrasive service