

## **THE COMPOUNDERS APPROACH TO DEVELOPING COMPOUNDS FOR COMPONENTS TO MEET MAJOR SPECIFICATIONS IN THE OIL AND GAS INDUSTRY**

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### **BIOGRAPHICAL NOTE**



Michael Winrow – Began his career in the Rubber Industry in 1992, after completing a BSc Hons degree in Polymer Science and Technology at Manchester Metropolitan University. He first started at Perrite Rubber Compounds then moved on to Leyland and Birmingham Rubber Company as the role of Development Technologist. In 2001 he joined Clwyd Compounders Ltd. as a Rubber Technologist and became Technical Manager in 2008, spearheading a team of experienced Rubber Technologists.

### **ABSTRACT**

Rubber compounds have been developed and used within the oil and gas industry for several years, many of which have been specifically designed to meet the various specifications and standards that are in existence. The key skill and function of the compounder is to formulate the material to satisfy the specification but at the same time to ensure that it has a low enough viscosity to allow sufficient flow during the moulding process to aid the formation of the part into a fully consolidated section, free from any defects.

The purpose of this paper is to highlight the paradox and dilemma between material properties and processability, discussing the issues involved in proposing suitable materials for this sector, and to show by clever compounding how serviceable parts can be produced.

### **INTRODUCTION**

Clwyd Compounders Ltd. was established in 1979; its original function to provide a service to jobbing moulding operations in the UK. In the 1980s the company was exploring new markets and looking for new opportunities which involved mixing high performance elastomer materials such as FKM.

Today Clwyd Compounders develops, formulates and mixes on site a full range of elastomeric materials with a portfolio that includes NBR, EPDM, HNBR, FEPM, FKM and FFKM (see Appendix 1 for more information).

Clwyd has provided compounds into the oil and gas sector for over twenty years.

## **1. THE RUBBER NEEDS FOR THE OIL AND GAS INDUSTRY**

Rubber compounds are used for numerous different applications and for a wide range of functions in the oil and gas sector, with many requiring a demanding set of criteria and specifications.

The hostile environments that elastomeric compounds must resist in service include sour gas (hydrogen sulphide) in combination with methane, carbon dioxide, water, sour crude oil and saline at elevated pressures above 1,000 bar and temperatures above 200°C. This has led to:

- The development of industry standards. The rubber compound must meet the requirements of the specification in order for the material to be used in the particular application.
- For other applications there are no specific standards but “serviceable compounds” are used.

### **a) THE STANDARDS**

The main standard is Norsok M-710, Rev 2, Oct 2001

This standard was applied by the Norwegian operators to subsea non metallic seals.

The two main aspects of the standard involve:

- Chemical ageing;
- Explosive decompression resistance.

Other standards include: American Petroleum Institute (API), National Association of Corrosion Engineers (NACE) and International Standards Organisation (ISO).

In terms of standards set by corporate groups, Shell have developed an Explosive Decompression (ED) Test – this is a gas pressure test designed to evaluate sealing elastomer performance (O ring) when subjected to multiple decompression events from 2000 psi

### **b) PRODUCTION OF “SERVICEABLE” COMPOUNDS**

Where there is no specific standard set, “serviceable” compounds have been developed over time for a number of different applications to meet certain criteria. These have mostly been derived from discussion with engineers taking into account the conditions the compound must face.

## **2. CONSIDERATIONS THAT MUST BE TAKEN INTO ACCOUNT WHEN COMPOUNDING FOR THIS SECTOR**

### **a) EXPLOSIVE DECOMPRESSION**

When an elastomer is exposed to a gas under high pressure, a certain amount of gas will dissolve and permeate into it. The higher the pressure, the larger the quantity of gas will be forced into the material. If the gas pressure is released slowly there is a good chance the trapped gas inside the elastomer will expand and may escape harmlessly into the atmosphere. However if rapid depressurization occurs, the trapped gas will expand violently as it tries to escape to the lower external pressure.

The explosive expansion of the gas within the confines of the elastomer can have damaging effects on the material. For example it can cause swelling, blisters, cracks or even total destruction of the rubber component. The severity of damage varies with the pressure applied, the rate of pressure drop, temperature, nature of gas or gas mixture, other contacting fluids, mechanical properties and the cross section of the component. Smaller sections perform better than larger sections due to these factors.

### **b) THE EFFECTS OF GASES ON ELASTOMERIC COMPOUNDS**

Gases can act in a physical or chemical way on elastomeric compounds and can be divided into three groups:

- Elements – Nitrogen, Oxygen, Hydrogen, Chlorine, Argon, Helium and Neon;
- Chemical compounds – Carbon Dioxide, Methane, Acetylene or vapours of Water, Ethanol and Benzene;
- Mixtures – Air, Fuel Vapours

The gases that act physically are Nitrogen, Methane, and Carbon Dioxide. These may cause damage by explosive decompression as explained above. Two possible ways to minimise this effect would be to:

- increase the depressurization time to allow the trapped gas to escape harmlessly;
- choose a very hard, high strength compound.

Gases that act chemically are reactive gases such as oxygen, ozone, chlorine and fumes of acids. These gases are very aggressive and can cause total destruction of the rubber part if the correct compound has not been used. It is therefore crucial that all ingredients of the compound are considered

### **c) ELASTOMER PERMEABILITY TO GASES AND VAPOURS**

While It is generally well understood that silicones have the highest permeability to gases followed by NR, EPDM, SBR, CR, NBR, FKM, ECO and IIR polymers, different compounds having the same base polymer can differ greatly in permeability rate due to the influence of compounding ingredients. For example, the incorporation of certain fillers lowers the gas permeability to a certain extent depending on the levels whereas large amounts of plasticiser increase the gas permeability. These additions can have a detrimental effect depending on the environmental the material encounters.

Furthermore, the permeability rate of various gases through different elastomeric materials varies in an unpredictable way depending on the size of the gas molecules and the solubility of the gas in the rubber compound in question. Permeability is also temperature dependant, increasing with higher temperatures. These factors must be taken into account when selecting a compound in this context.

### **d) DRILLING MUDS**

A further aspect which is often overlooked is the effect on the elastomer by substances used as drilling fluids, known as drilling “muds”. Muds are combinations of chemicals which are used to alleviate particular drilling production problems. These include hydrochloric acid, sulphuric acid, formic acid, hydrofluoric acid, inhibitors with amines, ketones and peroxides. These chemicals, particularly the amine based corrosion inhibitors, can attack the elastomeric component resulting in degradation and therefore premature failure. To illustrate, studies have been conducted on Caesium Formate used in drilling muds which has been shown to cause severe effects on elastomer materials. It is imperative that the chemical nature of the mud is considered when formulating a compound for a specific environment.

### **e) METHOD OF MANUFACTURE / SIZE AND SHAPE OF THE COMPONENT**

Materials that are used to make parts for this sector are usually very hard and have a relatively high viscosity and therefore are difficult to form into the required part. A moulder will generally prefer a lower viscosity compound for ease of processing and consequently this gives rise to a paradox. An experienced compounder is thus needed to advise the best balance of properties in a particular scenario.

The series of pictures in Figures 1, 2 and 3 are examples of a trial that Clwyd, with the help of two customers, ran to demonstrate the effects of material versus process.

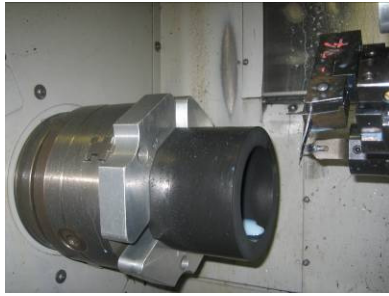
The objective was to produce a cylindrical packer unit by using a typical material in this case a Type 2 FKM compound 90 Shore A.

**Fig. 1 – Compression Moulding**



Compound was presented to the mould as a set of stacked rings. The material was subjected to high pressure and at cure temperature for the correct moulding time. The resultant part looked acceptable, but after a machining operation, cracks and flow line defects were evident. This was due to the high viscosity of the compound as there had been insufficient material flow within the moulding cavity to knit together the individual rings together.

**Fig. 2 – Transfer Moulding**



This image shows a lathe mounted cylindrical packer. The method adopted to manufacture the part in this case was transfer moulding. The material was forced through small holes under pressure to consolidate in the cavity. Despite the high hardness of the compound, this method enabled sufficient flow to form the part.

**Fig. 3 – Destructive Testing**



The part depicted in Fig. 2 was then destructively tested and inspected Fig. 3 illustrates that there were no flaws or blemishes evident and the material was fully consolidated (see numbered rings opposite). Therefore in this instance transfer moulding with this particular material proved a more suitable process than compression moulding due to the better consolidation and flow of material using this technique.

### 3. CLWYD COMPOUNDERS – CHALLENGING CONVENTION IN THE DESIGN OF COMPOUNDS FOR THE OIL AND GAS INDUSTRY

Clwyd Compounds Ltd. is known throughout the UK and Europe as the supplier of bespoke quality rubber compounds covering a broad spectrum of polymers from Natural through to the ultimate in Perfluorinated Rubber.

Clwyd has specialised in formulating compounds based on high performance elastomers to the oil and gas sector for over 20 years. One of the main dilemmas connected to this industry is the conflicting requirements of meeting the demands of carefully devised engineering specifications to provide optimum physical properties for the end-user but meanwhile facilitating the moulding of compounds by intermediary processors.

Clwyd has the requisite expertise to identify these issues and offer solutions, based on a strong technical team consisting of qualified and experienced rubber technologists. They can advise engineers or end users, using their vast experience and knowledge to formulate and develop suitable compounds by considering the requirements, conditions, material type and method of manufacture.

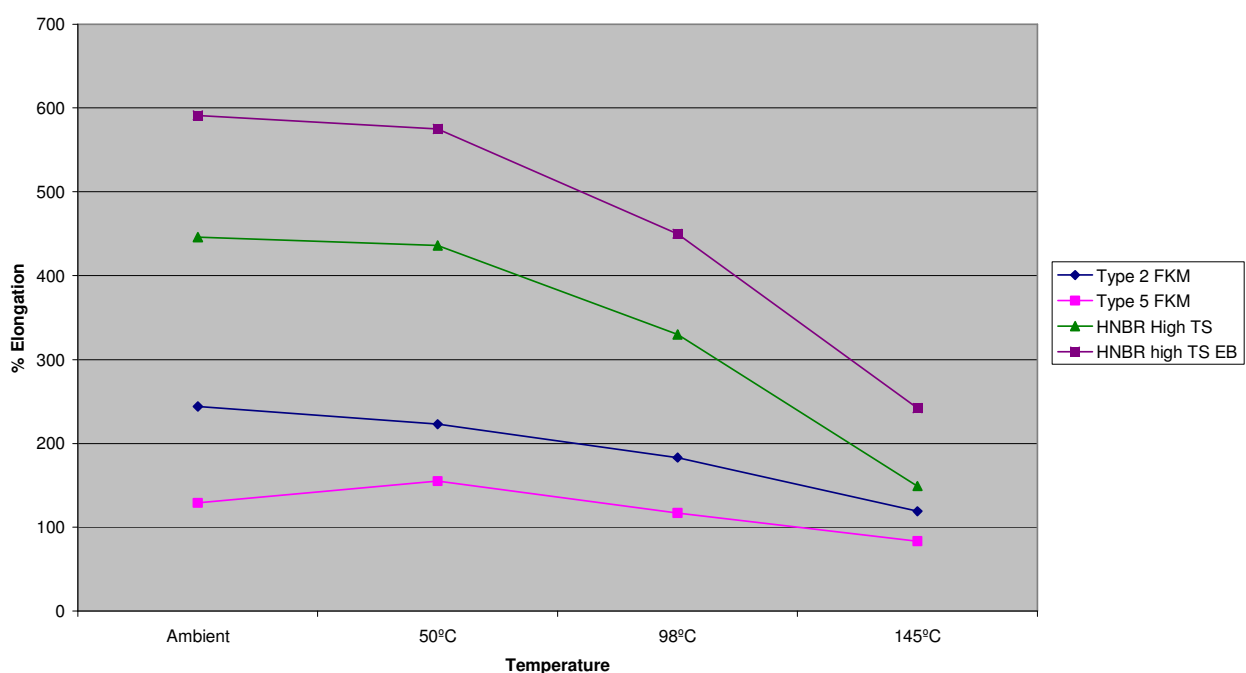
#### a) THE PARADOX BETWEEN MATERIAL SPECIFICATION AND PROCESSABILITY - EXAMPLES

Engineers often define a physical specification for a material without realising the consequence this restraint has on the ability to actually manufacture the component. The compounder must take into consideration the true needs of the component in the specific duty and take into account how the actual component needs to be manufactured.

For example, if one of the criteria of the compound is for a very high tensile strength at break, this tends to result in a lower elongation at break and correspondingly a high compound viscosity. Consequently it can be difficult to consolidate the material when moulding and in essence the component is weaker than the tested physical results show.

In addition, test results should be analysed carefully because the conditions and temperature the component must face in service may be totally different to those defined in standard specifications. Take for example the feature of tensile strength at lower extension i.e. the modulus value, with a high elongation being the more desirable property. Laboratory testing is normally conducted at ambient, but we know elongation reduces at elevated temperatures; (see Fig. 4) therefore a low elongation at break can result in failure at service temperature due to the specification not accounting for this phenomenon.

Fig. 4 - Temperature versus Elongation for a selection of high performance compounds



## 4. THE COMPOUNDER'S ROLE – CASE STUDIES

### 1 a) COMPOUNDS FOR GENERAL USE IN THE INDUSTRY - NBR ( Acrylonitrile Butadiene Rubber)

NBR is a polymer which is well known in the oil and gas industry for its very good resistance to petrochemicals. The general rule with regard to NBR is the higher the Acrylonitrile (ACN) content, the greater the oil resistance but poorer the low temperature flexibility. For this experiment we have selected the base polymer N33C50 at 100% which is a medium grade ACN.

The formulation series as shown in Fig. 5 has been set up to review a selection of compounding ingredients, fillers and viscosity modifiers in a standard NBR compound. The rationale behind this is to demonstrate how these types of ingredients can modify the physical properties and viscosity of the compound. The formulations for each compound are identical except for the changes to the silica fillers and viscosity modifiers (shown in bold as S1, S2, V1 and V2 in Fig. 5). Compound 1 is the benchmark formulation using only Precip. Silica (S1, 25 pphr); the remaining compounds use different combinations of S1, S2, V1 and V2 to highlight these effects.

**Fig. 5 – Formulation series**

Ingredient Type	Ingredient	1 Standard Compound	2	3	4	5	6
Polymer	N33C50 (NBR)	100pphr	100pphr	100pphr	100pphr	100pphr	100pphr
Vulcanising chemicals	Peg 4000	3	3	3	3	3	3
	Stearic Acid	1	1	1	1	1	1
	Zinc Oxide	5	5	5	5	5	5
	Sulphur 80%	0.6	0.6	0.6	0.6	0.6	0.6
	TMTD 80	2	2	2	2	2	2
	CBS 80	1	1	1	1	1	1
Antidegradant	Antioxidant	2	2	2	2	2	2
Fillers	FEF Black	5	5	5	5	5	5
	Talc	8	8	8	8	8	8
	<b>Silane Coupled Silica (S1)</b>			<b>25</b>	<b>25</b>		<b>25</b>
	<b>Precip. Silica (S2)</b>	<b>25</b>	<b>25</b>			<b>25</b>	
Plasticisers, resins, etc. (Viscosity modifiers)	<b>Transpolyoctene (V1)</b>		<b>10</b>	<b>10</b>			
	<b>Liquid NBR (V2)</b>					<b>10</b>	<b>10</b>

### b) SUMMARY OF COMPOUNDING INGREDIENTS

#### Vulcanisation chemicals

General systems are based on sulphur, accelerator and zinc oxide. These can be optimised to produce systems that offer good compression set and high resilience. Semi efficient vulcanisation systems have lower free sulphur content so that they are most suitable for transfer and compression moulding. Efficient vulcanisation systems using no elemental sulphur at all offer improved heat resistance to the compound. In the experiment the same semi EV system was chosen and used throughout the series.

In NBR sulphur is notoriously difficult to disperse therefore it is added early in the mixing cycle; failure to do this can result in parts with a textured orange peel finish. Metal oxides are required in sulphur curing, usually zinc oxide, but in certain cases a combination of zinc and magnesium oxides can improve the ageing resistance and the elongation to break.

#### Antidegradants

Antioxidants are added to NBR compounds to protect against oxidative degradation especially when the finished articles are subjected to dynamic stress or high temperatures. Chemically there is a wide range to choose from, dependent on service conditions and the type of accelerator system used. There are other

additives that can improve the flex cracking resistance of the vulcanisate and antiozonants can be used to impart a degree of ozone resistance.

### Filler systems

These ingredients are a key requirement to reinforce the NBR vulcanisate. The materials that are used in the main are carbon blacks but other fillers can also be added which enhance physical properties such as tensile strength and elongation at break. As polymer content is reduced with the corresponding increase in filler the swelling of the vulcanisate in oil and fuel decreases.

Silica fillers can be used to enhance tear strength and abrasion resistance, but associated problems of increased compound viscosity must be taken into account. Other additives such as glycols and silane coupling agents can be used to improve the processability, and inert filler such as microtalcs can be used to reduce the permeation of fuels. In the experiment combinations of fillers were used, precipitated silica and silane coupled silica were chosen to be evaluated across the mixes.

### Plasticisers, resins etc. (Viscosity Modifiers)

These ingredients are added to adapt the viscosity, tackiness, resilience, low temperature flexibility and swelling behaviour of the vulcanisates. Care must be taken when selecting ingredient types: synthetic esters and ethers are used for good low temperature performance; coumarone resins, factices are used to enhance building tack and to improve materials for processes such as calendaring and extrusion.

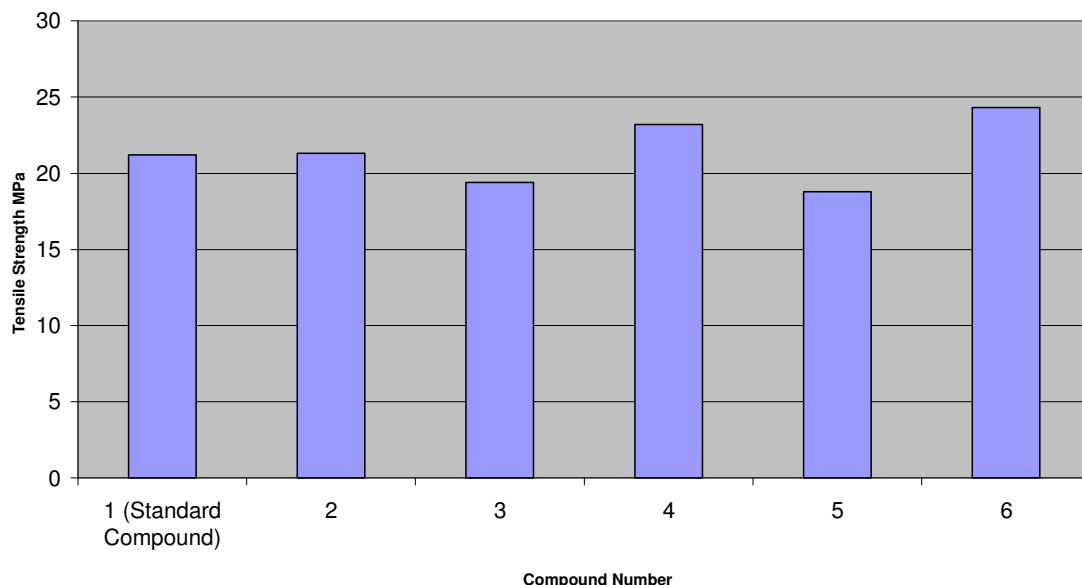
In the experiment a liquid nitrile plasticiser and a trans-polyoctene were used and their effects were recorded.

### c) ANALYSIS OF PHYSICAL TEST RESULTS

All compounds showed good physical properties (full test results provided in Appendix 2). Figures 6 - 10 show the relative values for tensile strength, elongation at break, modulus, Mooney viscosity and rheology comparison curves. The biggest difference was seen in the Mooney viscosity results, and it was expected that with the addition of the silane coupled filler and viscosity modifier in compounds 3 and 6 would provide the best scope in terms of processability without drastically affecting the physical properties.

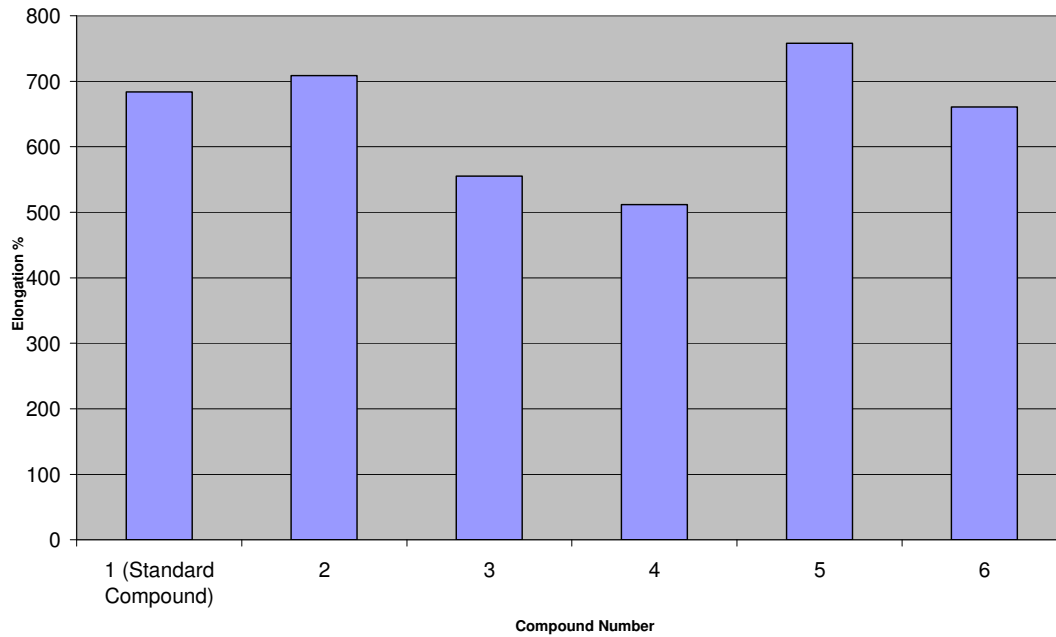
All tensile strength figures were in the region of 20MPa. This is a high strength value for this nature of compound.

**Fig. 6 – Tensile strength values for NBR compound series**



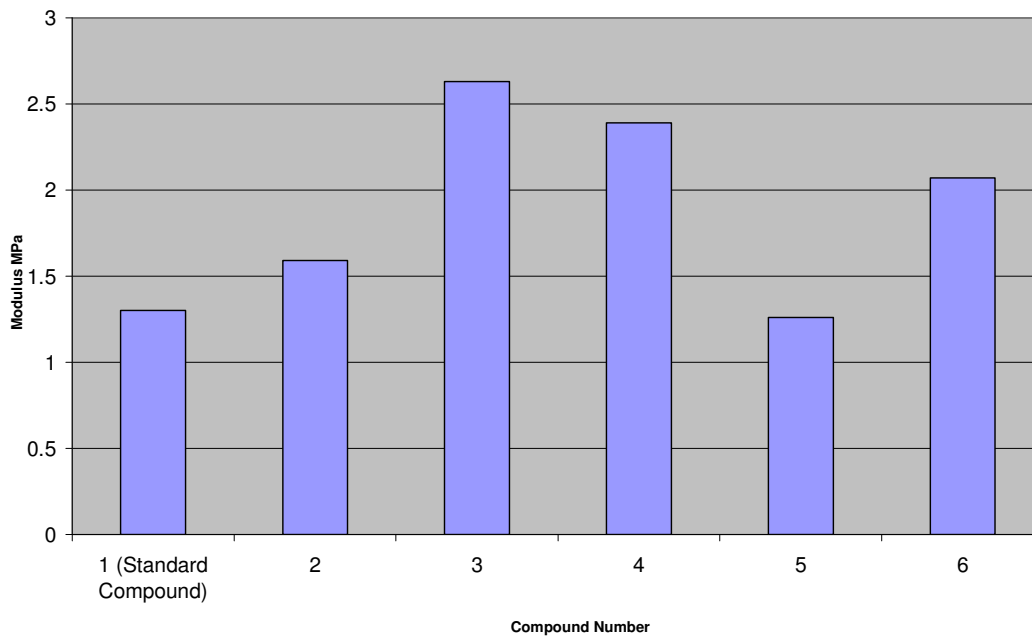
Compounds 3 and 6 were slightly lower in terms of elongation at break, due to the filler interaction and extension by the viscosity modifier. Nevertheless, results for all compounds were in excess of 500% which is a good value.

**Fig. 7 – Elongation at break values for NBR compound series**



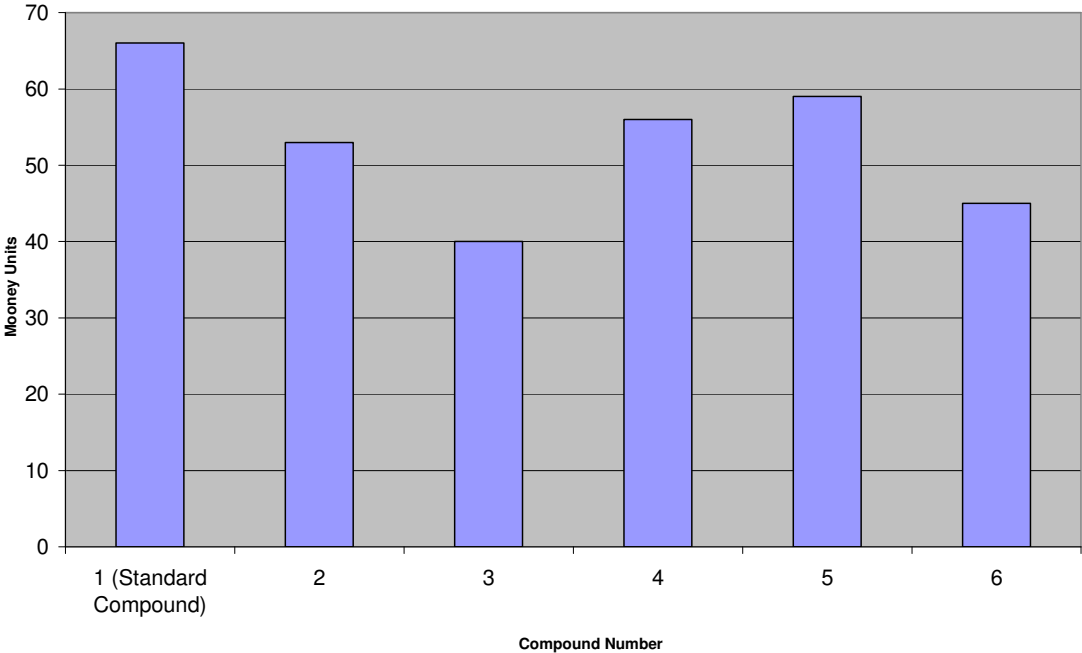
The modulus 100% value for the compounds using silane coupled silica was noted as being higher, due to the better filler interaction producing a tighter crosslink network within compounds 3, 4 and 6.

**Fig. 8 – Modulus 100% values for the NBR compound series**

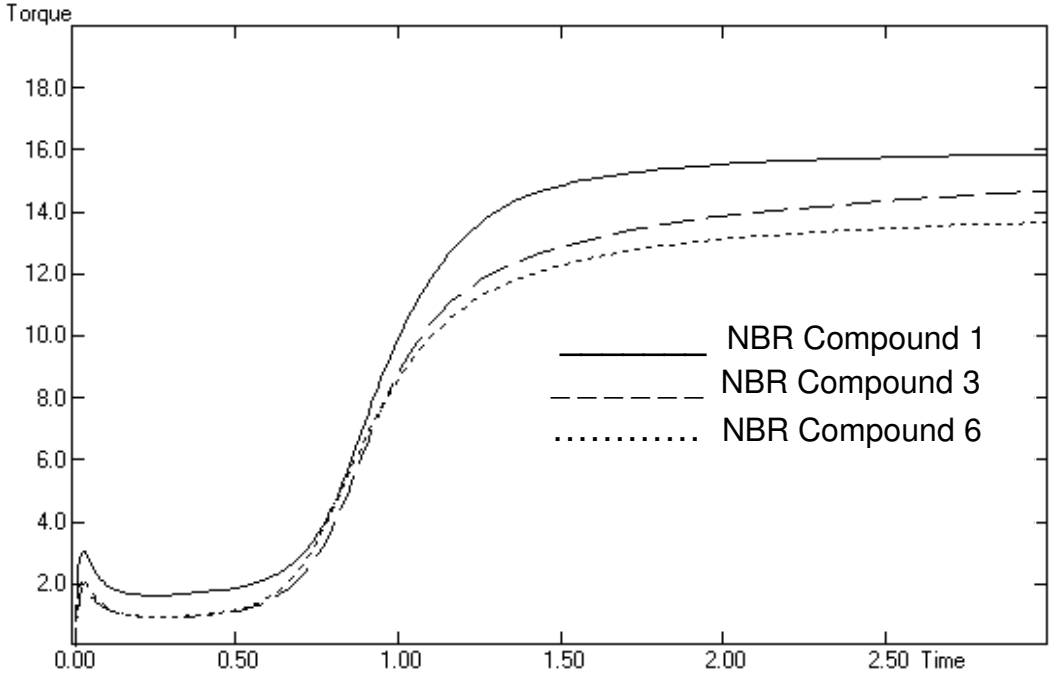


The rheology and mooney viscosity results show compounds 3 and 6 gave the lowest figures. Compound 3 included Transpolyoctene and Silane Coupled Silica and compound 6 included Silane Coupled Silica and Liquid NBR. These materials would have the added benefit of enhanced processability in processes such as transfer and injection moulding.

**Fig. 9 – Mooney Viscosity values – ML 1+4 at 100°C for the NBR compound series**



**Fig. 10 – Rheology Curves for NBR Compounds 1, 3 and 6**



This curve highlights the difference in rheological values between the key compounds.

#### d) SUMMARY OF PHYSICAL TEST RESULTS

The graphs illustrate that by using the chosen additives within this series of compounds the physical results maintained equivalent property value to the standard compound (compound 1). The main difference was noted with regard to the Mooney Viscosity values of compounds 3 and 6, which were considerably lower than compound 1. The rheology difference is also shown in Fig. 10. This would have a beneficial effect in aiding compound flow during the moulding process.

Therefore it is essential that the compounder has extensive knowledge and understanding of a broad spectrum of compounding ingredients, their function in terms of performance and processability to meet both end-user and intermediary processing requirements.

#### 2. HNBR (Hydrogenated Nitrile Butadiene Rubber) MATERIALS

HNBR is an oil resistant polymer that has an excellent property profile, which is attributable to the highly saturated polymer backbone in combination with the highly polar acrylonitrile functional group.

In comparison to NBR, HNBR has similar oil resistance but has superior chemical and heat resistance as well as improved physical properties over a wide temperature range. HNBR compounds are also formulated in a similar way to NBR in terms of the additives that are required, with the exception of the cure system which, due to the high saturation in HNBR, is predominantly peroxide.

By hydrogenation, the double bonds in NBR are eliminated and the butadiene bonds are transformed into polyethylene sequences. This gives HNBR the ability to crystallise under strain, resulting in high physical strength. HNBR compounds can be formulated to produce a material offering outstanding property balance including mechanical and dynamic as well as improved resistance to hot air, oils, chemicals and abrasion.

The following is an HNBR compound using high viscosity base polymer and high abrasion furnace black, this is typical of the types of materials that are being specified.

**Fig. 11 – Property profile and Rheology at 185°C of HNBR formulation A:**

Property	Result	Rheology Test	Result
Tensile strength	29 MPa	Min	5.24 dN/m
Elongation at break	244%	Max	42.4 dN/m
Modulus 50%	4 MPa	T05	0.38 min
Modulus 100%	10.7 MPa	T50	1.21 min
Hardness	83 IRHD	T90	2.96 min

The material offers excellent physical properties from the lab test sheet results as can be seen above. The resultant high tensile strength of 29MPa is attractive but the consequence is a very high minimum viscosity as shown in the rheology results which makes successful manufacture of viable parts very difficult; it could limit the manufacturing techniques and the ability to form the material into the desired shape so that it is fully consolidated and defect free. If defects are evident in the moulded section the part will be much weaker than the actual physical test results suggest.

Here is an example of a material that is designed to have a high elongation at break and high tensile strength at elevated temperature, but is also capable of being used to manufacture large articles by transfer moulding. It is designed for medium sour conditions, to be retrievable and for ease of actuation.

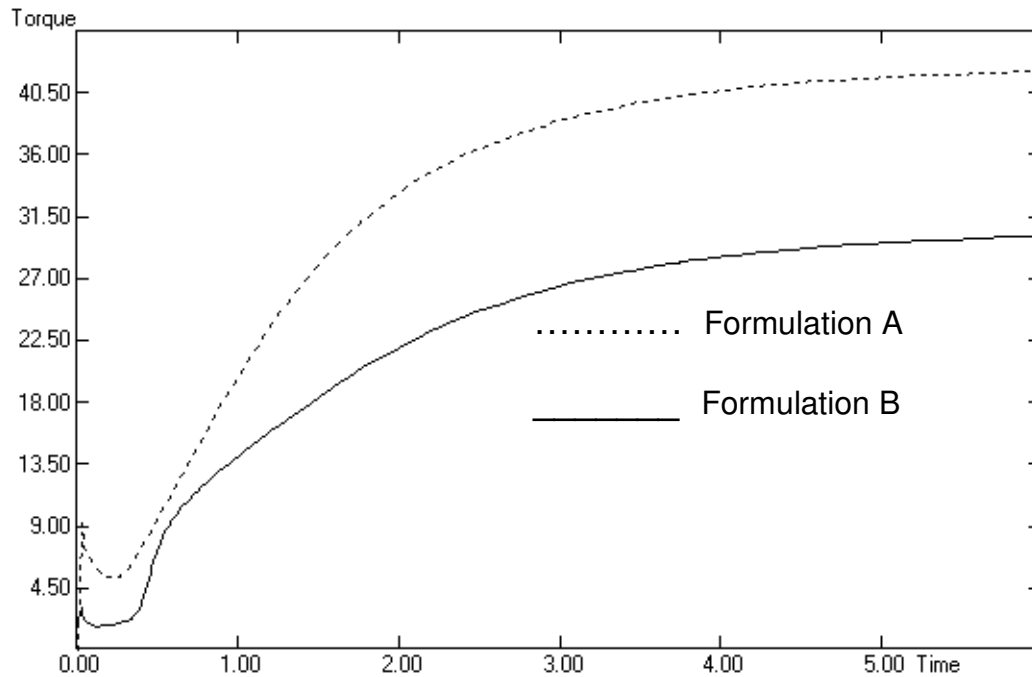
**Fig. 12 – Property profile and Rheology at 185°C of HNBR formulation B:**

Property	Result	Rheology Test	Result
Tensile Strength	18.8 MPa	Min	1.6 dN/m
Elongation at break	445%	Max	29.06 dN/m
Modulus 50%	3.4 MPa	T05	0.40 min
Modulus 100%	5.1 MPa	T50	1.21 min
Modulus 200%	9.6 MPa	T90	3.30 min
Modulus 300%	13.9 MPa		
Modulus 400%	17.4 MPa		
Hardness	82 IRHD		

The HNBR formulation B exhibits a very good physical property balance of high tensile strength but more importantly a high elongation to break. This is critical in high temperature performance as stress-strain properties are known to diminish at high temperature.

The rheology curves below show that the compound has a very low viscosity; this will have a beneficial effect of enabling the material to be transfer moulded into thick section parts such as a packer element, as the low viscosity will enable flow of material in the mould cavity and full consolidation and knitting to produce a flaw free part. This also means the tested data will be representative of the actual moulding.

**Fig. 12 – Rheology Curves for HNBR Formulations A and B**



### 3. FKM (Fluoroelastomer) MATERIALS

FKM is a nomenclature for a very wide and diverse range of fluoroelastomer materials, and the grades vary in terms of monomer makeup, fluorine content and molecular weight. The choice of particular FKM polymer type will depend on the conditions that the material has to face in service.

In general, FKM materials are resistant to a wide range of well fluids and chemicals, with the exception of the amine based corrosion inhibitors. These amines may cause dehydrofluorination of the conventional FKM elastomers, which would lead to severe hardening and embitterment, so it is essential to select the appropriate FKM compound to suit the specific oil and gas duty.

Due to the chemistry of these materials there is less scope for the compounder to modify the viscosity as there is a reduced number of potential compounding ingredients to select from. Therefore, the focus is placed much more on the properties of the polymers that are available.

The example in Fig. 13 is an FKM (terpolymer based), high hardness compound that has been formulated for a specific purpose in the oil and gas sector and is currently in service.

**Fig. 13 – Property profile and Rheology at 185°C of FKM formulation A:**

Property	Result
Tensile strength	14.3 MPa
Elongation at break	142%
Modulus 50%	8MPa
Modulus 100%	11.5 MPa
Hardness	95 IRHD

Rheology Test	Result
Min	6.37 dN/m
Max	34.6 dN/m
T05	0.98 min
T50	3.95 min
T90	7.99 min

The compound's physical results show that the material has a very high hardness of 95 IRHD, in combination with high tensile and modulus values and reasonably good elongation. The resultant high minimum viscosity (as shown in the rheology figures) was due to the choice of high viscosity base polymer, as discussed for ED resistance and the high structure carbon black combination that was required. Nevertheless, due to the thermoplastic nature of FKM materials there was sufficient flow in order to process the compound by transfer moulding. (See figures 1, 2 and 3 under heading titled Method of Manufacture / size and shape of the component, earlier in the paper).

#### 4. FEPM (Aflas ®) MATERIALS

The main advantage of using these specific fluorinated polymers is that they have particularly good base resistance in general, and are also resistant to steam and Hydrogen Sulphide, which can be present in variable concentrations in oil wells. Formulating FEPM materials to obtain a good balance of properties requires relatively few ingredients. Selecting the correct polymer base, filler and curative package is critical to the end performance of the compound in both processing and function; other types of ingredients are occasionally added to enhance specific properties.

**Fig. 14 – Typical FEPM formulation**

Ingredient	Level (phr)
TFE Elastomer	100
Reinforcing filler(s)	5 – 60
Peroxide(s)	1 - 5
Coagent(s)	1 – 10
Process aid(s)	0.5 - 5

Formulation A is a FEPM 90 compound that is typical of the type proposed in this field. It is based on a FA-100H polymer and uses a combination of carbon blacks to give the required reinforcement and high hardness. This polymer has the highest molecular weight available and is used for compression moulded goods in very demanding physical environments.

**Fig. 15 – Property profile and Rheology at 185°C for FEPM formulation A**

Property	Result	Rheology Test	Result
Tensile Strength	23.8 MPa	Min	7.82 dN/m
Elongation at break	135 %	Max	80.38 dN/m
Modulus 50%	8.4 Mpa	T05	0.67 min
Modulus 100%	15.9 MPa	T50	1.73 min
Hardness	91 IRHD	T90	3.88 min

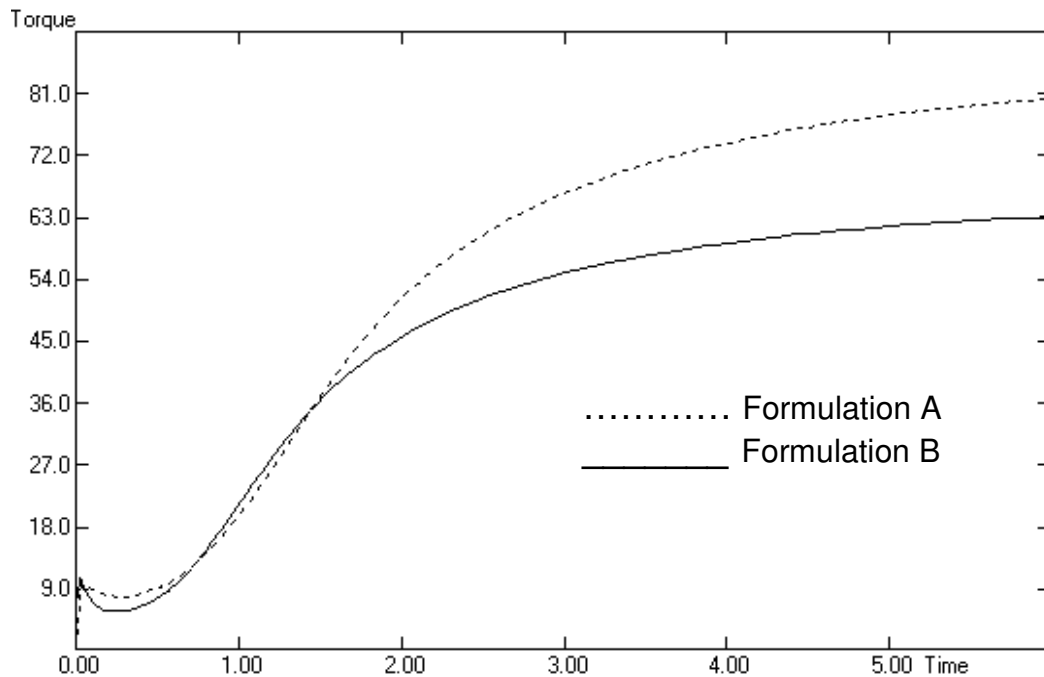
Compounds for use in oilfield environments are often high modulus in order to resist extrusion caused by the high differential pressures found down hole. The high modulus can be achieved by ensuring the compound has a high crosslink density and use of the more reinforcing fillers.

Here is an example of a FEPM based material (formulation B) that Clwyd has formulated to suit particular purposes in the oil and gas sector. It is designed to have good explosive decompression, steam, hydrogen sulphide resistance balanced with the ability to be moulded easily. The rheological difference between formulation A and B can be seen in Fig. 17.

**Fig. 16 – Property profile and Rheology at 185°C for bespoke FEPM formulation B**

Property	Result	Rheology Test	Result
Tensile Strength	19.9 MPa	Min	5.74 dN/m
Elongation at break	115 %	Max	63.05 dN/m
Modulus 50%	9.7 Mpa	T05	0.56 min
Modulus 100%	17.6 MPa	T50	1.42 min
Hardness	94 IRHD	T90	3.47 min

**Fig. 17 – Rheology Curves for FEPM Formulations A and B**



The physical test results show a high hardness material with a good all round physical property profile; these results are typical of compounds used in the oil and gas sector. In terms of achieving the balance between viscosity and good physical strength, it will have the benefit of the improved processability, and so will make the task of producing a perfect part easier. The absence of flow lines and stresses within the moulding will ensure that the test results achieved in the laboratory will be replicated in the moulded part.

## **CONCLUSION**

This paper demonstrates that with skilled formulating and close consideration of both the needs of the end-user and intermediate processors, it is possible to produce functional compounds for highly demanding applications in this sector. The objective is finding the right balance of physical properties and compound viscosity, using the appropriate blend of compounding ingredients and fully understanding their functions within the material.

## **FURTHER WORK**

Clwyd Compounders actively seek new materials and ingredients to develop into viable compounds that have advantages over competitive compounds; these can be evaluated in our development system.

## **ACKNOWLEDGEMENT**

The author gratefully acknowledges the help and assistance provided by the Clwyd Compounders team and the help given by John Kerwin of Precision Polymer Engineering with the engineering of parts in Figures 1, 2 and 3.

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The following books provide general background reading into the subject:

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Modern Fluoropolymers – John Scheirs

Rubber Technology Handbook Hofmann

The Manual for the Rubber Industry - Bayer

Rubber as a Engineering material – Khairi Nagdi

HNBR for use in Oilfield Applications- Rubber World Aug 2007 by John Dato, E. C. Campomizzi, D. Achen.

## **APPENDIX 1 - Abbreviations**

NR	Natural Rubber
SBR	Styrene Butadiene Rubber
NBR	Acrylonitrile Butadiene Rubber
CR	Chloroprene Rubber
HNBR	Hydrogenated Acrylonitrile Butadiene Rubber
EPDM	Ethylene Propylene Diene (Monomer) Rubber
ECO	Epichlorohydrin Rubber
IIR	Butyl Rubber
FKM	Fluoroelastomer
FEPM	Tetrafluoroethylene Propylene Rubber (Aflas® - Asahi Glass)
Type 2 FKM	Fluoroelastomer Terpolymer
Type 5 FKM	FEPM (Viton® ETP - Dupont, Aflas®)
API	American Petroleum Institute Standards
NACE	National Association for Corrosion Engineers
ISO	International Organisation for Standardisation
EV	Efficient Vulcanisation
ED	Explosive Decompression

**APPENDIX 2 – Table of physical test results of compounds moulded for 8 Minutes at 165°C**

Compounds		1 Standard Compound	2	3	4	5	6
Test	Unit						
Hardness	IRHD	57	61	66	68	57	59
Tensile	MPa	21.2	21.3	19.4	23.2	18.8	24.3
Mod 100%		1.3	1.59	2.63	2.39	1.26	2.07
E@B	%	684	709	555	512	758	661
Density	g/cc	1.3	1.15	1.15	1.19	1.17	1.18
Comp set 24hrs at 100°C	%	15	20	16	14	17	18

**Heat Aged 168hrs at 100°C**

Hardness change	IRHD	+8	+7	+6	+6	+7	+7
Tensile change	%	+9	-11	-3	-12	+5	-14
Elongation change	%	-8	-7	-16	-25	-8	-25

**Fluid Resistance ASTM 1 - 168hrs at 100°C**

Hardness change	IRHD	-3	-4	0	+2	-5	+1
Tensile change	%	+10	-9	+6	-13	+7	-11
Elongation change	%	-6	-5	-17	-27	-9	-27
Volume change	%	-1	+1	-0.2	-2	-1	-2

**Rheology at 165°C**

Min	dN/m	1.77	1.44	1.05	1.28	1.61	1.05
Max	dN/m	17.53	14.61	17.52	22.71	14.79	17.43
T05	min	1.4	1.32	1.5	1.35	1.24	1.3
T50	min	2.34	2.2	2.39	2.21	2.21	2.22
T90	min	3.56	3.12	7.32	8.72	3.39	7.5
ML 1+4 at 100°C	Moon ey Units	66	53	40	56	59	45