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Classification of flints for drill wear potential

Mohammed Musa Aliyu,
Institute of Applied Geosciences, School of Earth and Environment, University of Leeds, Leeds, UK
William Murphy,
Institute of Applied Geosciences, School of Earth and Environment, University of Leeds, Leeds, UK
Richard Collier
Institute of Applied Geosciences, School of Earth and Environment, University of Leeds, Leeds, UK
Institute of Applied Geosciences, School of Earth and Environment, University of Leeds, Leeds, UK
James Anthony Lawrence
Radioactive Waste Management Ltd, Nuclear Decommissioning Authority, Dicot, UK

ABSTRACT: The assessment of abrasiveness and hardness of rocks have been extensively covered by previous researchers, with little attention to flints, which were only described as highly abrasive. However, analysis of flints has shown that abrasivity of flints varies. These parameters are important inputs for the prediction of drill bit wear rate and design of various parts of drilling/tunneling/mining equipment. In this paper, a classification of flints (sampled from the English, French and Danish Chalk) which correlates with the abrasivity and hardness of flints is proposed. The results showed lighter/grey flints (with more calcite) have lower potential to cause drill bit wear as indicated by hardness and geotechnical wear indices than dark flints. This tends to suggest that even small variations in the carbonate content results in significant variation in abrasivity and that colour can be used as an indication of the potential of flints to cause tool wear.

1 INTRODUCTION

In most continents, flints are found either as nodules, sheets or as extensive thick beds (tabular) in chalk. Encountering flints during engineering works usually leads to challenges affecting the entire project execution/costs. These threats are among the major factors affecting engineering projects in chalk. The problems are in the form of abrasive wear of drilling/tunneling tools, which are mostly felt during excavation because they were not envisaged at the preliminary stage of the project. This usually leads to costly changes or redesign of both the project or excavation machinery and associated cutting parts (Hahn 1999, Mortimore 2012 and Varley 1990). Therefore, proper understanding of wear properties of flints will help in predicting their potential to cause drill tool wear, and will also aid in the design of excavation systems before onward mobilisation to the field.

Unfortunately, despite the persistent threats posed by flints, the hardness and abrasiveness of flints are not well understood and attempts to understand these are very limited. Similarly, to date, no attempt has been made to relate the hardness and abrasiveness of flints to their various colours. Thus, this paper looks at the wear properties of flints using Shore Hardness (SH, n= 39), Cerchar Abrasivity Index (CAI, n= 71), X-Ray Diffraction (XRD, n= 14), Vickers Hardness Number of Rock (VHNR, n=14), Rock Abrasivity Index (RAI, n= 108), Scanning Electron Microscopy and

Image analysis (ImageJ). These methods were used to determine the abrasive properties of flints and to define which flint has more chance of causing drill wear, when characterized by colour. The aim is to establish a simple classification of flints for prediction of tool wear rate based on colour variation, for use at the preliminary phase of site investigations.

2 MATERIAL AND METHODS

Flint samples were collected from Chalk outcrops at multiple study sites (Fig. 1 and Table 1 for sampling details). Four flint colours comprising grey (g), light grey (Lg), dark brownish grey (Db) and light brownish grey (Lb) were considered for this study. SH and CAI of flints were measured in accordance with ISRM (2007) and Cerchar (1986) procedures respectively (Figs. 2a and 2b for results). XRD of flints was determined from flint powder. The mineral phases were identified and quantified using Bruker EVA search Match software and Bruker TOPAS respectively. The Equivalent Quartz Content (EQC) of flints as described in Thuro (1997) was estimated using equation 1. The results of XRD and EQC analyses are in Fig. 3.

SEM analysis was conducted on rough flint chips and the images generated were analysed using ImageJ image analysis software to properly define the degree of silica cementation among the flint types (Figs. 5a-f for results).

Table 1. Sampling locations of Upper Cretaceous flints used for this study

Locations	Formations	Coordinates
North Landing (NLF)	Burnham	[54°7' N, 0°6'W]
Ulceby Vale House Quarry (LS)	Burnham	[53°36' N, 0°19'W]
Birling Gap, East Sussex (SUK)	Seaford	[50°74' N, 0°24'E]
Haute Normandy, Dieppe (SFr)	Seaford	[49°93' N, 1°06'E]
Picardy, Mesnil-Val (LFr)	Lewes	[50°05' N, 1°33'E]
Sigerslev Quarry, Stevns Klint (SKT)	Tor	[55°19' N, 12°26'E]
Møns Klint (MKT)	Tor	[54.°59' N, 12°32'E]

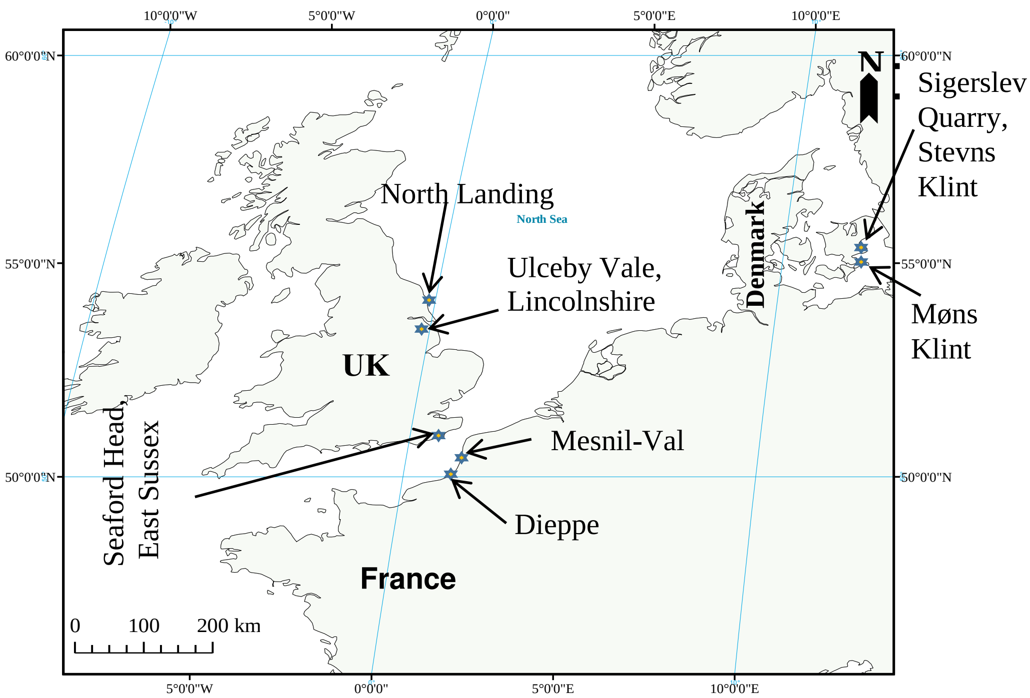

Figure 1. Study locations.

$$\mathrm{EQC} = \sum_{i=1}^{n} A_\mathrm{i} \cdot \mathrm{R}_i \quad (1)$$

where EQC = Equivalent Quartz Content (%), A_i = mineral content (%), R_i = Rosiwal Grinding Hardness (%); for quartz =100 and for calcite=2, and n = is the number of minerals in the sample.

The VHNR and RAI of flints were determined as described in Plinninger (2010) using equations 2 and 3 respectively.

The results of these indices are shown in Figs. 4a and 4b respectively.

$$\mathrm{VHNR} = \sum_{i=1}^{n} VHN_\mathrm{i} \cdot \mathrm{A}_i \quad (2)$$

where VHNR = Vickers Hardness Number of Rock ($kgmm^{-2}$), VHN=Vickers Hardness Number ($kgmm^{-2}$) which is 1161 for quartz and 157 for calcite, and A_i = mineral content (%).

$$\mathrm{RAI} = \sum_{i=1}^{n} R_\mathrm{i} \cdot \mathrm{A}_i \cdot UCS \quad (3)$$

where RAI = Rock Abrasivity Index, A_i (%), R_i (%) and n are as defined in equation 1, and UCS = Uniaxial Compressive Strength (MPa).

3 RESULTS AND DISCUSSION

Hardness Index Parameter: The hardness, abrasiveness and regression graphs/results of the flints investigated are shown in Figs. 2-6. The Shore Hardness (SH) results (Fig. 2a) showed that grey flints are slightly softer (82-100) than the dark brownish grey flints (112-115). The SH values reduced when lighter zones of grey and dark brownish grey flints were tested. Differences in SH also exist between grey flints from the North Landing site and Ulceby quarry, Lincolnshire, despite being of the same colour; this is thought to be due to microfractures observed in the North Landing flints being absent in the latter.

Cerchar Abrasivity Index (CAI): In Fig. 2b, CAI results show the light grey and light brownish grey flints 2.85-3.57 (0.1mm) were slightly less abrasive than the grey and dark brownish grey flints 3.29-4.59 (0.1mm). Generally, the abrasivity of most of these flint materials can be classified as very abrasive (see Cerchar 1986), with few extremely abrasive cases. Most of these CAI values appear to be underestimates because the test was conducted on smooth sawn surfaces, where the Cerchar pins only glide over the samples leaving a shiny impression without grooves, suggesting poor abrasion of the samples.

Mineral Composition: XRD analysis results presented in Fig. 3 show grey flints possessed 98-98.86% α-quartz, rising slightly to 98.50-99.50% for dark flints and with values of 76-93% and 93-99% for light grey and light brownish grey flints respectively (Fig. 3). The remaining percentages are dominantly calcite.

Geotechnical Wear Indices: The EQC of flint materials (Fig. 3) ranges from 98.56 to 99.51% for dark brownish grey flints and 96.60 to 99.13 for light brownish grey (Fig. 3). The EQC for grey flints ranged from 98.13 to 98.88%, while 76.49 to 92.98% was recorded for light grey flints.

VHNR values for grey flints (Fig. 4a) range from 1141-1150 $kgmm^{-2}$, while for dark flints these values range from 1136-1155 $kgmm^{-2}$. These are consistent with VHNR results reported in Latridou et al. (1986) for Grand-Pressigny flints. A conspicuous reduction in VHNR between grey and light grey flint was observed. In addition, a slight variation was observed between the VHNR for dark brownish grey flints and that for light brownish grey flints (1098-1152 $kgmm^{-2}$).

RAI results (Fig. 4b) generally indicate that dark brownish grey flints record highest RAI values from 152 to 938, with site averages ranging from 390 to 550. Lower RAI values ranging from 24 to 603 were recorded for Grey flints, with RAI site averages of 305 for the Ludborough flint from Lincolnshire, and 110 for Ludborough flints in the tectonically disturbed chalk from North Landing. Thus, based on the RAI results, grey flints may be classified as very abrasive materials corresponding to very low bit lifetime. A few competent grey flints and all dark brownish grey flints fall into the extremely abrasive category, corresponding to extremely low drill bit lifetime. This classification based on the drill bit lifetime prediction graph described in Plinninger (2010) was developed for rock samples with a maximum RAI of 200, which is far less than the RAI values RAI values of most flints. Therefore, the possibility of a skewed classification might not be ruled

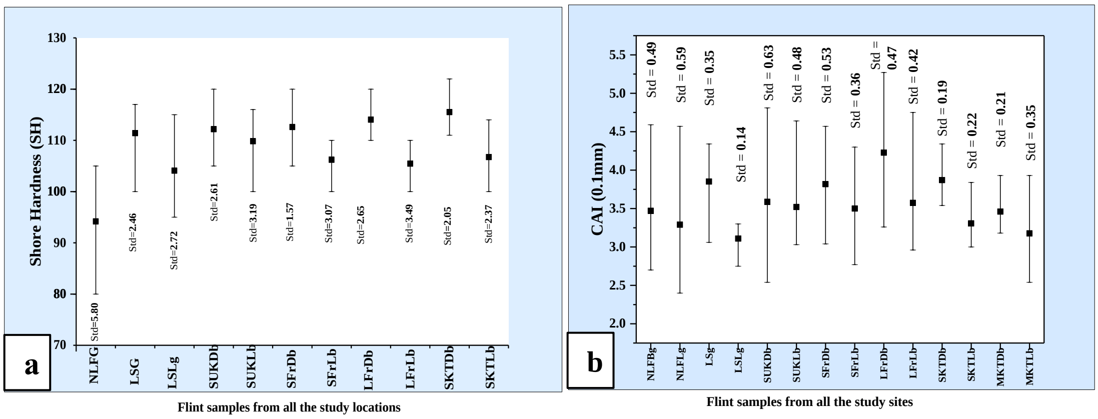

Figure 2. (a) Shore Hardness and (b) Cerchar Abrasivity Index against different flint samples.

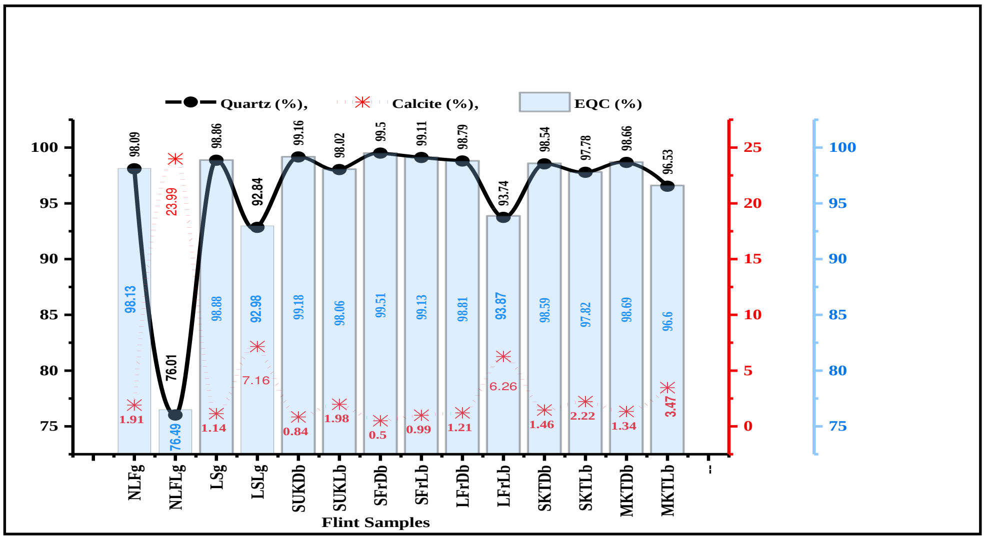

Figure 3: XRD results depicting mineral composition of flints; and Equivalent Quartz Content (EQC). Note: The alphabets g, Lg, Db, Lb attached to end of the sample titles are respectively for grey, light grey, dark brownish grey, and light brownish grey flints.

out, hence a need to review this prediction graph so that hard materials such as flints can be incorporated.

SEM analysis (Figs. 5a-c) shows the dark flints have a high degree of silica cementation, as emphasized by image analysis (Figs. 5d-f), where the red spots represent granular quartz crystals and the white areas (larger in the dark flints) represent massive silica cementation or the agglomeration of quartz crystals.

Variation between the flint colours was only slightly manifested in CAI, VHNR and EQC, but is seen with respect to RAI and SH. This is confirmed by the graphs (Fig. 6), where a weak correlation is seen between RAI and CAI ($R^2 = 0.40$), VHNR ($R^2 = 0.44$) and EQC ($R^2 = 0.44$), but

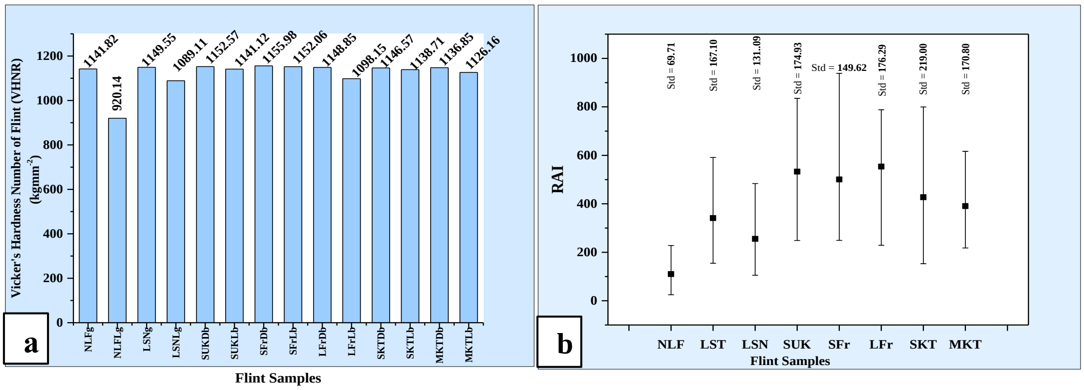

Figure 4. (a) Vickers Hardness Number of Rock; and (b) Rock Abrasivity Index (RAI) against flint samples.

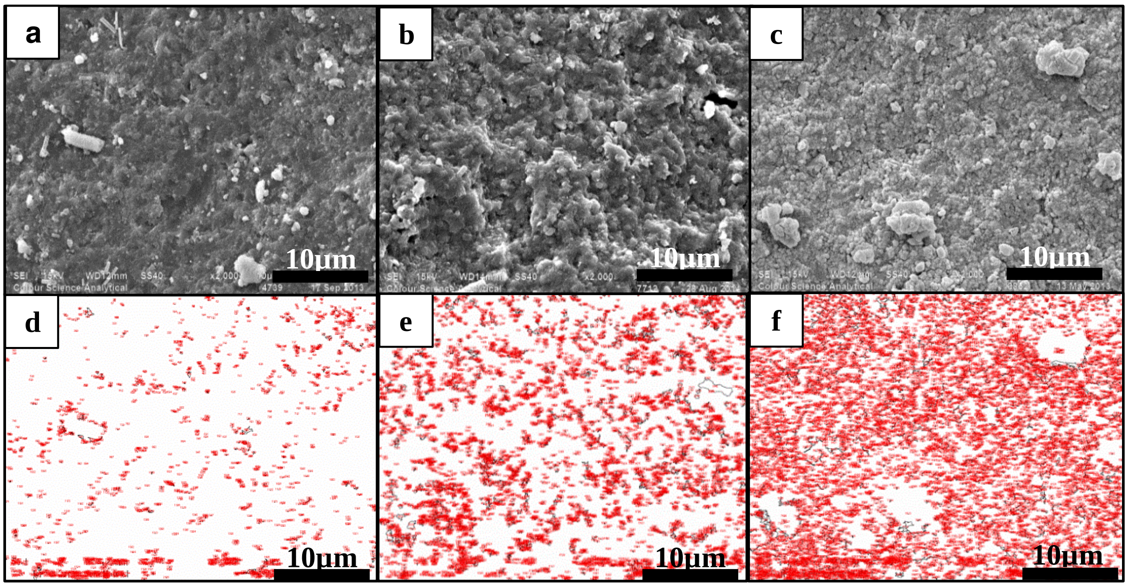

Figure 5. SEM and ImageJ analyses: (a,d) Dark brownish flint, Seaford Chalk Formation France (SFrDb); (b,e) Grey flint, Burnham Chalk, Ulceby Vale House Quarry, Lincolnshire (LSg); (c,f) Light brownish grey (NLFLb) flint, Burnham Chalk Formation, North Landing.

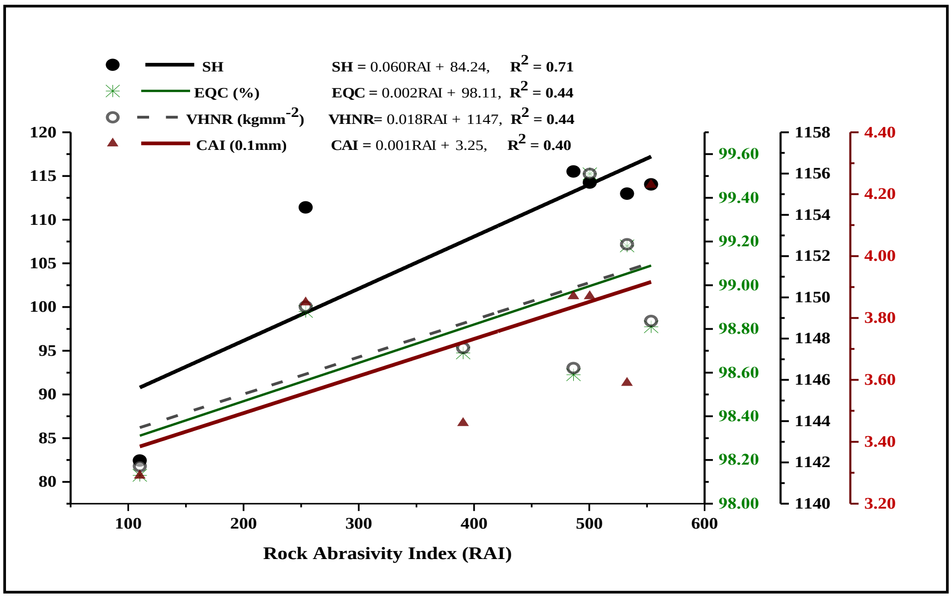

Figure 6. SH vs RAI (%); EQC (%) vs RAI; VHNR (kgmm-2) vs RAI; CAI vs RAI.

a stronger correlation is seen with SH (R^2=0.71). For CAI, this was due to poor contacts between the Cerchar pin and the quartz grains due to the hardness and microcrystalline nature of flints. The weak correlations of RAI vs VHNR and RAI vs EQC are because these methods rely on abrasive mineral contents as the major control on abrasiveness, whilst in addition to mineral composition, microtexture and compressive strength of flints also account for the wear potential of flint materials. For RAI against SH, a correlation is stronger due to the implicit consideration of compressive strength in the two methods. However, the correlations described above are derived for comparison using the present data; applying models derived from these correlations for prediction might need additional data.

4 CONCLUSIONS

In this paper SH, CAI, XRD, EQC, VHNR, RAI, SEM and image analysis were used to determine the abrasiveness and hardness of different types of flint materials. The results show that wear parameters of flints vary with colour and strength. The lighter/grey flints (with more calcite content) have the least potential to cause drill wear, while the dark brownish flints (with more quartz) have the highest. This suggests that even slight differences in carbonate content can lead to significant variation in abrasiveness and hardness of flints. The results suggest that colour variation can be used as a predictor of tool wear. The results also suggest that existing drill bit wear rate prediction models and graphs do not account for extremely hard materials like flint. Further work should consider the current findings with a view to developing updated wear rate prediction graphs/models, which incorporate flint materials.

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