OPTIMISATION OF THE POLISHING PROCESS FOR PORCELAIN CERAMIC TILES

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ABSTRACT

Polishing is a very important process in porcelain tile manufacturing, and accounts for a large proportion of the total cost of the product. In current industrial practice the sequence of abrasive sizes used in polishing, and the time for which the tile is exposed to each abrasive, is largely based on experience. Previous studies of tile polishing have concluded that different sizes of abrasives have different effects on improving the tile surface during polishing processes, i.e. decreasing surface roughness and increasing gloss. There may be opportunities to reduce the cost and improve the quality of the final product by optimising the process, through quantitative analysis of the development of surface finish during polishing.

In earlier work presented by the authors at QUALICER 2004, a laboratory-scale polishing rig was developed and shown to replicate accurately the relevant aspects of conditions in an industrial polishing line. This equipment has been used to explore the development of gloss and roughness in a full sequence of abrasive grit sizes, using standard commercial abrasive compounds containing silicon carbide grit in a magnesium oxychloride cement binder, and porcelain ceramic tiles. It was found that with a full sequence of 14 different grit sizes (from 36 to 1500 mesh size) the surface changes measured in the laboratory matched those observed in an industrial process using the same sequence of grit sizes. However, analysis of the laboratory data showed that certain sizes of abrasive sizes had much less effect on gloss and roughness than others, and an abbreviated sequence of only nine sizes was therefore explored. It was shown that essentially the same final surface finish could be produced by using this shorter sequence at the laboratory scale, and these results have also been validated in pilot-scale tests in a full-size polishing rig.

The final polishing stages, with abrasives of 1000 and 1500 mesh sizes, were recognised to be most important in controlling the final gloss. A sequence of polishing tests with different combinations of smaller abrasives (grit sizes 1000 and 1500) was therefore also carried out to explore the optimum polishing process.

The results of this work suggest that there may be economies to be gained in commercial tile polishing, by the use of a restricted set of abrasive sizes. Advantages may result from a reduced number of polishing stages, with a resulting reduction in abrasive consumption, or at least in a reduction in the range of abrasive sizes required to be held in stock for replacement purposes.

1. INTRODUCTION

Polishing is a very important process in the production of high-quality unglazed porcelain tiles, and accounts for a large proportion (typically more than 40%) of the total cost of the product. The polishing operation employs a succession of stages (typically twenty to thirty) with steadily decreasing abrasive particle size. The abrasive particles, usually silicon carbide, are embedded in a cement matrix to produce composite tools which are mounted on a rotating polishing head which presses against the tile surface. In current industrial practice, the sequence of abrasive sizes used in polishing, and the time for which the tile is exposed to each abrasive (which may be carried on one or more polishing heads along the production line), is largely based on experience.

Previous studies of tile polishing have concluded that different sizes of abrasives have different effects on improving the tile surface during polishing processes, i.e. decreasing surface roughness and increasing gloss. The larger abrasive particles (typically with grit numbers below 400, corresponding to particle sizes above about 35 μm) have the most effect on the surface roughness, while the smaller particles (with grit numbers above 400) have the greatest effect on the gloss[1-3]. The aim of the work reported in this paper was to explore the possibility of reducing the cost of polishing, and even perhaps improving the quality of the final product, by optimising the polishing process.

A laboratory-scale polishing rig has been developed and shown to replicate accurately the relevant aspects of conditions in an industrial polishing line; its design was reported at QUALICER 2004[1,2]. This equipment was used to replicate the sequence of steps used in a typical industrial polishing line, and to explore the development of gloss and roughness for a full sequence of abrasive grit sizes. Results from these tests were then used to design a shorter sequence of polishing steps, which was then tested at a laboratory scale, scaled up to a pilot-scale machine, and finally implemented in trials on a full-scale industrial polishing line.

2. EXPERIMENTAL METHODS AND MATERIALS

In the industrial polishing process, the tiles pass on a conveyor beneath a sequence of polishing heads, each of which carries a set of six abrasive blocks and rotates about a vertical axis. The head incorporates a mechanism to move each block in a swinging motion, in order to achieve a cylindrical surface on the block over which the wear of the abrasive material is distributed. The polishing process is defined by the sequence of abrasive particle sizes used in the heads, by the speed of the tiles along the line, and by the rotation speed of each head and the downward force it applies. A typical line may employ up to about 30 heads, usually with two or in some cases even more heads carrying the same size of abrasive particles. The tile surface is flushed with water to lubricate the process, provide cooling and remove the debris.

The conditions of contact pressure and abrasive/tile kinematics in the industrial process have been analysed in earlier work and used to design a laboratory-scale apparatus to reproduce the key features[1, 2]. This rig was used to perform laboratory-scale experiments at the University of Cambridge. In this apparatus, the abrasive material is in the form of a short cylinder, 12 mm diameter and 12 mm long, which is pressed on to the surface of a rotating square tile sample (100 mm square), as shown in Figure 1. The conditions used for the laboratory-scale tests were as follows: rotational speed of tile 300 rpm; rotational speed of abrasive pin 150 rpm; applied load 17 N. A standard polishing time of 30 seconds corresponded to approximately the same extent of abrasion (number of passes of the abrasive over a point on the tile surface) as that experienced by a tile passing under a single head in a typical industrial polishing process.

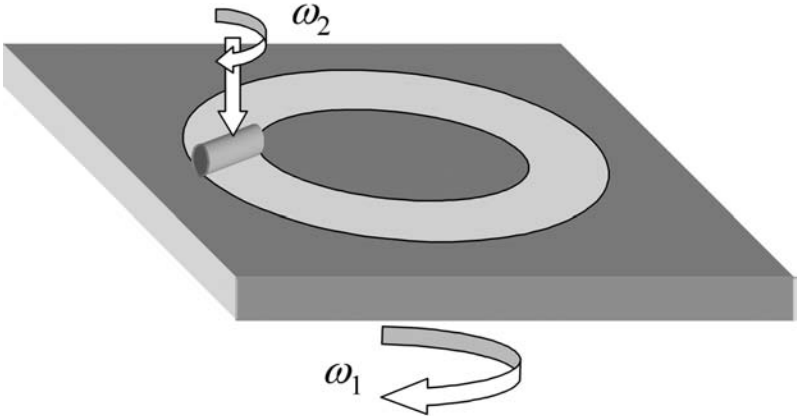

Figure 1. Schematic diagram of the laboratory-scale rig, showing the motion of the square tile sample (with rotational speed ω_1) relative to the abrasive pin (rotational speed ω_2)

Pilot-scale tests were carried out at ITC, Castellón, with a purpose-designed rig consisting of a single industrial polishing head (Ancora s.p.a., Italy) mounted above a reversible conveyor belt; full control over the system allowed conditions in an industrial line to be reproduced for the polishing of single tiles. Full-scale tests were then performed on an industrial polishing line (Levitile Iberica S.A., Spain).

All the tests used standard commercial abrasive blocks containing silicon carbide grit in a magnesium oxychloride cement binder, and high-quality porcelain ceramic tiles produced by a commercial process. At various stages in the polishing process, the tile surfaces were characterised by measuring their roughness (RA) and optical gloss (G) at a standard angle of incidence of 60º.

3. RESULTS AND DISCUSSION

3.1. LABORATORY-SCALE TESTS

Figure 2 shows the evolution of surface finish in tests at laboratory-scale using a full sequence of abrasive grit sizes, representative of industrial practice (36, 46, 60, 80, 100, 120, 180, 240, 280, 320, 400, 600, 1000, 1500 mesh). For each abrasive size up to and including 1000 mesh, the sample was polished for 60 seconds, corresponding to passage under two heads in an industrial line. The samples were then polished for three sequential periods of 60 seconds each with the finest (1500 mesh) abrasive. It has been shown that with the full sequence of 14 different grit sizes (from 36 to 1500 mesh size) the surface changes measured in the laboratory closely matched those observed in an industrial process using the same sequence of grit sizes[1, 2].

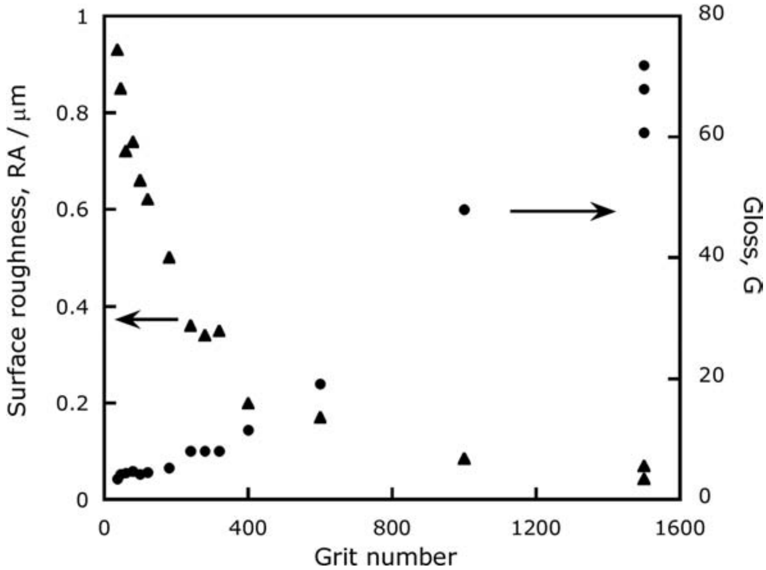

Figure 2. Evolution of surface roughness and gloss of the tile surface as a function of grit number (mesh size) for the full sequence of polishing steps (as described in the text) in the laboratory-scale rig.

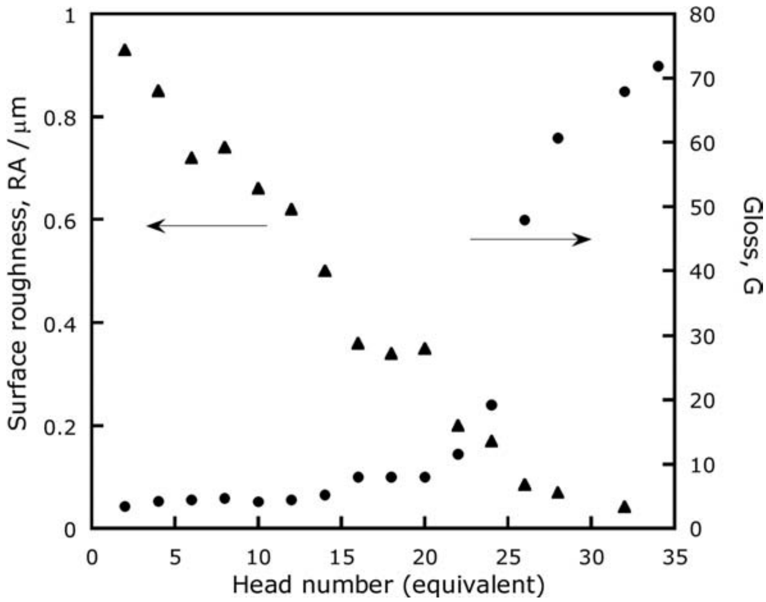

Figure 3. Data from Figure 2 re-plotted in terms of the equivalent number of polishing heads in an industrial line.

However, if these data are re-plotted in terms of the equivalent number of polishing steps (i.e. as a simulated sequence of stages through the heads on an industrial line), as in Figure 3, it is clear that certain sizes of abrasive have much less effect on gloss and roughness than others. It was also found that most of the changes produced by a particular abrasive size occurred in the first 30 seconds of polishing (corresponding to passage under a single head in an industrial line). An abbreviated sequence using only ten sizes of abrasive (mesh sizes 36, 46, 60, 100, 180, 240, 400, 600, 1000, 1500) was therefore explored. The tile sample was polished for 30 seconds with each size (corresponding to passage under a single head), except for the 1500 mesh which was used for periods of 30, 60, 90, 120 and 150 seconds. The results are plotted in Figure 4, in terms of the grit number (Figure 4a) and the equivalent number of polishing heads (Figure 4b). They show that, in principle and under laboratory conditions, essentially the same final surface finish (with a final gloss level of about 70%) could be produced by using this shorter sequence of 14 heads, as that resulting from a sequence of 34 heads in a simulated industrial sequence. Significant further reduction in the number of polishing stages is probably not attainable, even under ideal conditions. In translating these findings to the industrial scale it is clear that some redundancy is needed, so that worn abrasive blocks can be replaced without the need to stop the line.

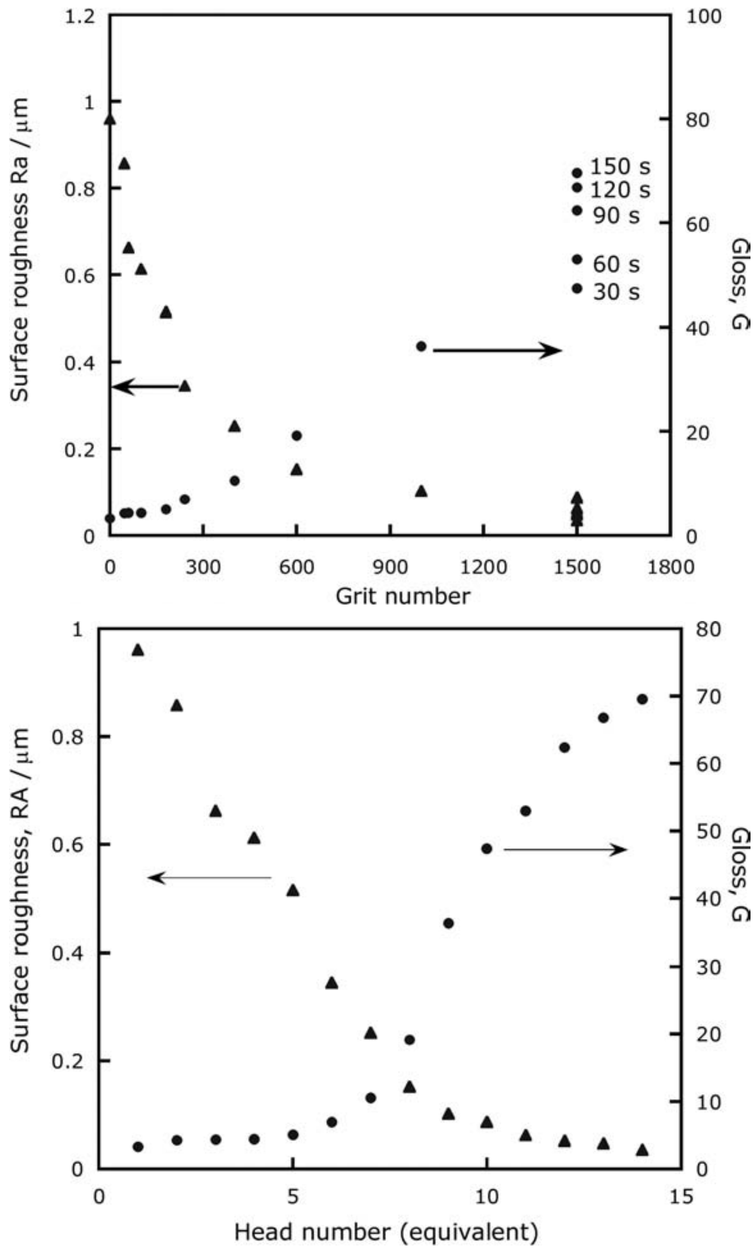

Figure 4. Evolution of surface roughness and gloss of the tile surface as a function of grit number (mesh size) for the abbreviated sequence of polishing steps (as described in the text) in the laboratory-scale rig. (a) upper graph: data plotted in terms of abrasive grit size; (b) lower graph: data plotted in terms of the equivalent number of polishing heads in an industrial line.

3.2. PILOT-SCALE AND FULL-SCALE INDUSTRIAL TRIALS

Further tests were carried out with the pilot-scale rig to establish whether the abbreviated sequence described above could be implemented on a larger scale. Tests were performed with the following sequence of nine grit sizes: 46, 60, 80, 150, 220, 320, 600, 1000, 1200. For each abrasive size the minimum polishing time achievable corresponded to the action of between one and two heads in an industrial line. Evolution of both gloss and roughness was measured and found to be very similar to that seen in the laboratory-scale tests, and trials were therefore conducted on a full scale.

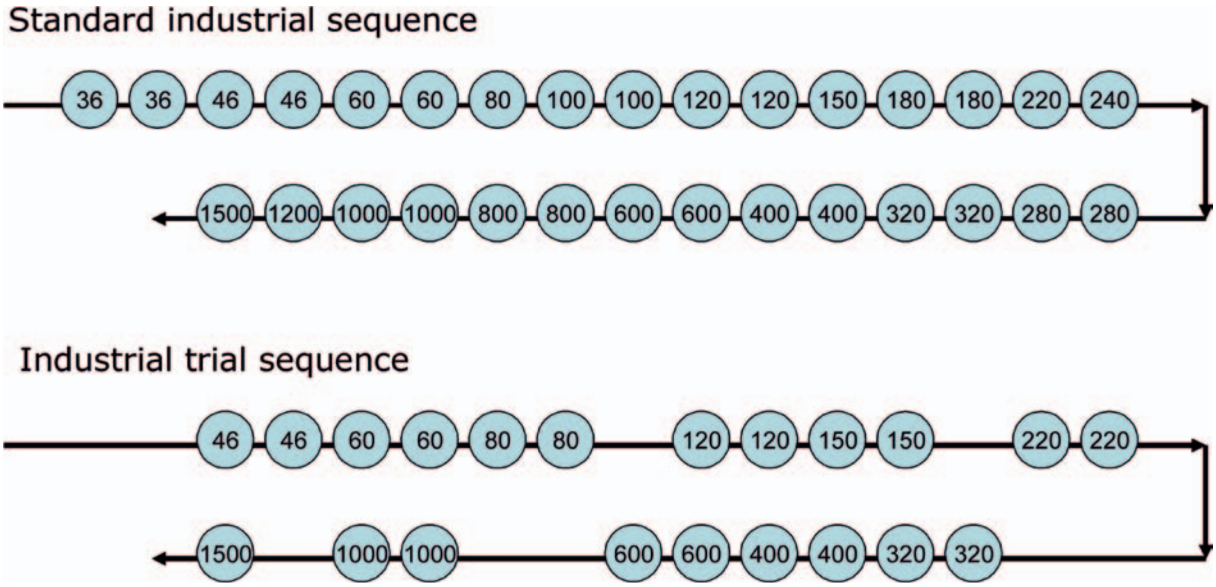

Figure 5. Abrasive grit sizes used in the sequence of polishing heads in the standard full-scale line (upper diagram) and in the abbreviated sequence used in the industrial trials (lower diagram).

The standard sequence of abrasive sizes used in the industrial polishing line is shown in Figure 5, and employed 18 different sizes on 30 polishing heads. The industrial process also used an additional final stage with even smaller abrasive particles (lux), but for the purposes of these experiments that stage was not used. The performance of the standard process was compared with the results from a sequence of 11 grit sizes: 46, 60, 80, 120, 150, 220, 320, 400, 600, 1000, 1500 mesh, on 21 heads. In each case except 1500 mesh, two heads were used for each grit size to provide some redundancy; there was only a single head carrying 1500 mesh abrasive, as shown in Figure 5.

Once steady conditions had been established in the line, it was halted and tile samples withdrawn at each stage for measurement of roughness and gloss. The results are shown in Figure 6. Figure 6a shows the evolution of roughness and gloss with grit number, for measurements taken on the industrial line with the standard sequence of heads used for normal production (red circular points) and with the abbreviated sequence described above (blue triangles). The data for gloss are also plotted in Figure 6b in terms of the number of polishing heads.

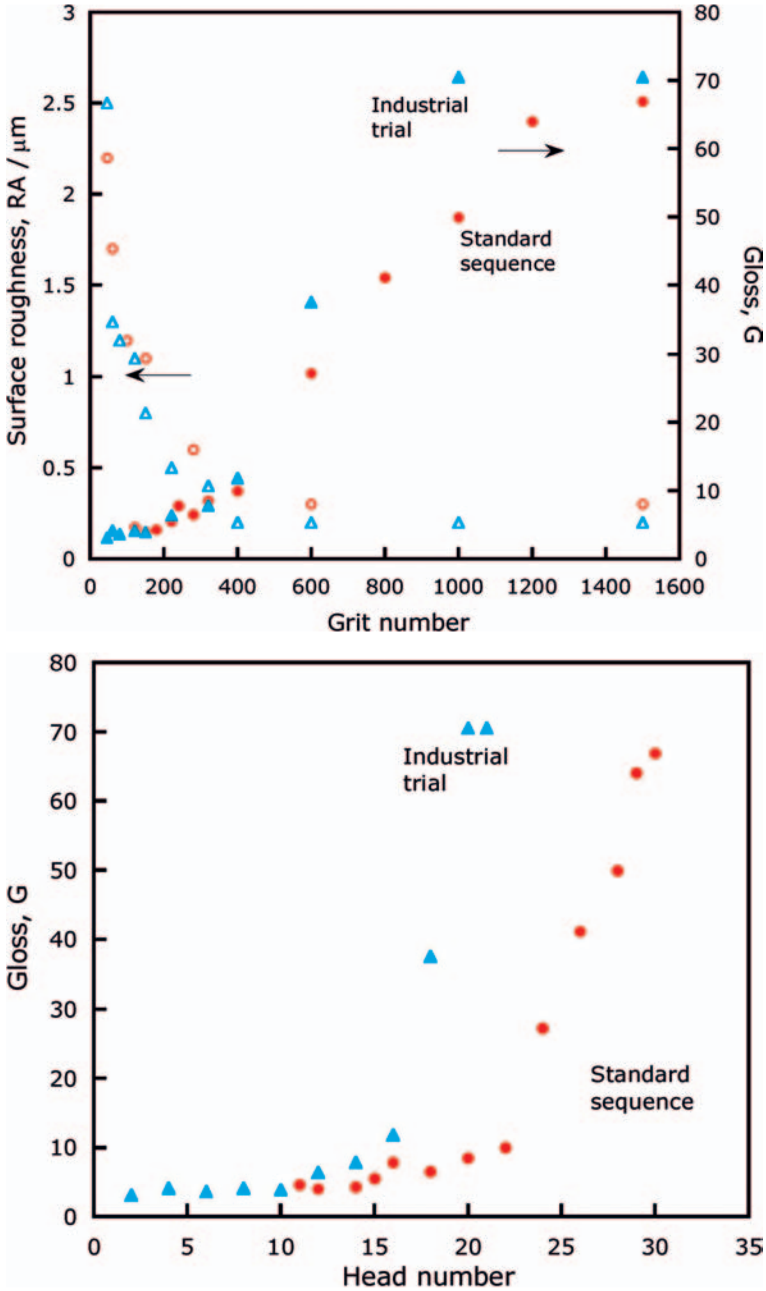

Figure 6. Evolution of surface roughness and gloss for tiles withdrawn from the industrial polishing line for the standard sequence of polishing steps (red points) and for the abbreviated sequence used in the trials (blue points): (a) upper graph: data plotted in terms of abrasive grit size; (b) lower graph: data plotted in terms of the number of polishing heads.

The results in Figure 6 clearly show the potential benefits of the abbreviated sequence, in which essentially the same final gloss value of about 70% was achieved by polishing with a sequence of 21 heads, compared with 30 heads in the standard process.

The sequence used in the full-scale trials is almost certainly capable of further refinement. Even with the system investigated here, however, there could be significant potential benefits from several sources. The reduction by 33% in the number of heads in use would correspondingly reduce energy consumption and equipment replacement and maintenance costs. There would also be a reduction in the consumption of abrasive blocks, in the labour needed to replace the blocks and maintain the line, in the number of replacement blocks needed to be stocked on the factory floor at any time, and in the range of sizes of abrasive to be stocked. The reduction in the number of heads carrying the larger abrasive particles (<400 mesh number) represents a 35% saving, and since it is the larger abrasive particles which remove the most material from the tiles[3], this would result in a corresponding reduction in the amount of polishing debris produced by the process.

The reduction in the amount of material removed from the tiles could, however, lead to a higher proportion of defective products if sufficient depth is not removed to compensate for the damage and defects introduced in the initial planing and calibration stages of the process; these aspects would have to be considered in any practical implementation of the results of this investigation.

4. CONCLUSIONS

The results of this work suggest that there may be economies to be gained in commercial tile polishing, by the use of a restricted set of abrasive sizes. Essentially the same final gloss levels were achieved with a reduction by one third of the number of polishing heads in a full-scale industrial line. It is possible that even further reductions might be attainable. Significant advantages may result from a reduced number of polishing stages, which could lead to a reduction in abrasive consumption, power consumption, plant maintenance costs and labour costs and in the range of abrasive sizes required to be held in stock for replacement purposes; there would also be benefits in a reduction in the amount of polishing debris produced by the process.

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