UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL DETERMINATION OF SAFE SERVICE LIFE OF MOTORCYCLE HELMET

AZHAR HAMZAH

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By

AZHAR HAMZAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

May 2016

DEDICATIONS

I would like to dedicate this work to:

ALLAH SWT for His Blessings

My beloved mother who is always there for me, anytime and every time…….

Zainab Mohamad

My significant other, my dear wife who relentlessly keeps supporting…….

Intina Pandak

My enthusiastic children, who keep asking for answers

Ainaa, Alyaa, Alif

My siblings and friends, who keep the spirit up

Thank you for all the supports, guidance, encouragements and trusts

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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May 2016

Chairman : Professor Wong Shaw Voon, PhD
Faculty : Engineering

The most distressing trauma in motorcycle crashes is head injury which has caused over 50% of motorcyclist death. Such rate stresses the importance of an effective protective equipment, the motorcycle safety helmet. Helmet protects by reducing the impact forces from reaching the users' heads upon impact contact. New helmets performance is well assured, however, after a certain period of use, their performance may deteriorate to less than optimum due to environmental and use factors such as ultraviolet exposures and unintentional drops/impacts. There is scarce information on the impact performance of used helmet. This performance is usually measured by headform acceleration in laboratory test.

This study attempts to determine used helmet impact performance with regards to headform acceleration performance in impact test. It intends to determine used helmet headform acceleration performance relative to service age, examine headform acceleration performance at critical side and identify factors affecting used helmet headform acceleration performance.

The study involves performing impact test in an established test facility, SIRIM QAS, Shah Alam. It utilises the Malaysian helmet standards protocol, MS1:1996, as the basis for conducting experiment and acquiring the headform acceleration values. In brief, 65 helmet samples were collected randomly near Kajang and Semenyih townships. These helmet varies in service ages and in a number of physical attributes such as shell and liner thickness, though all were certified to the same test standards when new. 10 of 65 helmets (15.4%) were not tested due to failure in complying with the fit-for test criteria. 55 helmets were impact tested at four sides per helmet (front, right, left and rear) and the variables studied were headform acceleration, service age, helmet mass, shell thickness, liner thickness and density, impact speed and impact energy. Two different impact severities were adopted, impact velocities of 6.4 m/s

onto a flat anvil and 5.8 m/s onto an hemispherical anvil. Helmets were randomly numbered and during test, the test order was systematically change to minimize bias.

The test result indicated the helmets have a wide spectrum of service ages, from 6 months to 167 months with a mean of 65 months. It reveals the retention pattern of helmet in the nearby townships. In addition, almost all helmets were capable of meeting the headform acceleration limit ($\leq 300g$) at different impact severities, despite all the conditions they may have gone through during use tenure. The key reason for the positively high pass to fail rate (96.4%) was possibly the filtering process of helmet samples which had basically removed a substantial number of helmets not fit-for-test (15.4%). Statistically, there were significant correlations of helmet headform acceleration to the service age, helmet mass, liner thickness, shell thickness and impact energy ($p<0.05$). There was no significant different of impact performance between the four impact sides ($p>0.05$). Helmet deterioration measurement was not quantified due to lack of baseline information. The samples make and model were not identifiable in many cases and the certification information is confidential.

The study also attempts to model headform acceleration with the assumption that the relationships between all independent variables (service age, helmet mass, shell thickness and liner thickness) and dependent variable (headform acceleration) was linear. Comparison of two aged helmets, 27 and 37 months showed that the prediction for higher impact energy (111J) was relatively closed to the actual test result (around 5%), however for lower impact energy (96J), the variation exceeds 18%. The linear assumption has limit the model applicability to a service age range of 24 months. Moreover, the small sample size of helmets (N=55) may not allow any deduction of conclusive evidence for any generalisation. A strict filtering process to qualify helmet for impact test may have removed important data and should be reconsidered in future work for more representative and conclusive information.

In short, the study has presented meaningful information on used motorcycle helmet impact performances relative to headform acceleration and associated factors. It has also established introductory data on helmet retention and performance pattern for motorcyclists.

Key words: *Motorcycle helmet, headform acceleration*

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Master Sains

**EKSPERIMEN PENENTUAN JANGKA HAYAT SELAMAT
TOPI KELEDAR MOTORSIKAL**

Oleh

AZHAR HAMZAH

Mei 2016

Pengerusi : Profesor Wong Shaw Voon, PhD
Fakulti : Kejuruteraan

Salah satu trauma yang merisaukan ialah kecederaan kepala yang menjangkau lebih 50% sebab kematian pengguna motorsikal. Kadar yang tinggi ini menekankan lagi kepentingan alat perlindungan, iaitu topi keledar keselamatan motorsikal. Topi keledar melindungi dengan cara menyerap daya impak daripada mengenai kepala pengguna ketika impak berlaku. Prestasi helmet baharu adalah terjamin, namun begitu, selepas satu tempoh penggunaan, prestasi topi keledar boleh menurun lebih rendah dari tahap optima disebabkan oleh faktor persekitaran seperti sinar ultraviolet dan impak yang tidak disengajakan. Maklumat berkaitan prestasi impak topi keledar terpakai amat kurang. Pada kebiasaannya, prestasi ini diukur oleh kadar pecutan alat 'headform, didalam ujian makmal.

Kajian ini berusaha untuk menentukan prestasi topi keledar terpakai melalui pecutan 'headform' ketika ujian hentakan. Ia akan cuba menentukan pecutan 'headform' berkait dengan umur penggunaan topi keledar, menguji pecutan dibahagian yang kritikal dan mengenalpasti faktor-faktor yang mempengaruhi pecutan 'headform'.

Kajian ini melibatkan ujian hentakan yang dilaksanakan di makmal ujian, SIRIM QAS, Shah Alam. Ia menggunapakai peraturan ujian standard topi keledar, MS1:1996 sebagai asas dan pengumpulan data pecutan. Secara ringkas, 65 biji topi keledar dikumpul secara rambang dari bandar Kajang dan Semenyih. Topi keledar ini berbeza daripada segi umur dan ciri-ciri fizikal seperti tebal cengkerang dan lapisan penyerap, walaupun semuanya telah lulus pengesahan standard yang sama ketika baharu. 10 dari 65 biji topi keledar (15.4%) tidak diuji kerana kegagalan menepati syarat-syarat layak untuk diuji. 55 biji topi keledar telah diuji, dengan setiap topi keledar dihentak pada 4 sisi (depan, kanan, kiri, belakang) dan pembolehubah yang diuji ialah pecutan 'headform', umur penggunaan, jisim topi keledar, tebal cengkerang, tebal dan ketumpatan lapisan penyerap, kelajuan hentakan dan tenaga hentakan. Dua jenis hentakan, kelajuan hentakan 6.4 m/s keatas tukul rata dan 5.8 m/s keatas tukul separa

bulat. Topi keledar telah dinomborkan secara rambang dan ketika ujian, susunan sisi diubah secara sistematik bagi mengurangkan keputusan yang berat sebelah.

Keputusan ujian menunjukkan sampel topi keledar mempunyai jurang umur penggunaan yang luas, daripada 6 bulan hingga 167 bulan, dengan umur purata 65 bulan. Ia mendedahkan corak penyimpanan topi keledar di bandar berdekatan. Sebagai tambahan, hampir semua topi keledar berjaya melepasi tahap lulus ($\leq 300g$) pada tahap kesukaran berbeza, walaupun telah melalui pelbagai cabaran semasa tempoh penggunaan. Kemungkinan tahap lulus yang tinggi ini (96.4%) berkait dengan proses penapisan kelayakan untuk ujian hentakan yang telah mengeluarkan topi keledar yang tidak layak. Secara statistic, ada perkaitan penting antara pecutan 'headform' dengan umur penggunaan, jisim topi keledar, tebal penyerap hentak, tebal cengkerang dan tenaga hentakan ($p<0.05$). Tiada perkaitan penting prestasi impak antara empat sisi yang diuji ($p>0.05$). Kemerosotan kualiti topi keledar tidak dapat disukat disebabkan ketiadaan maklumat asas. Kebanyakan jenama dan jenis topi keledar tidak dapat dikenal pasti dan maklumat persijilan dirahsiakan.

Kajian ini cuba membangunkan model mudah berkaitan pecutan 'headform' dengan andaian perkaitan antara pembolehubah bebas (umur penggunaan, jisim topi keledar, tebal cengkerang dan tebal lapisan penyerap) dan pecutan 'headform' adalah berkadar terus. Perbandingan antara dua biji topi keledar berumur 27 dan 37 bulan menunjukkan anggaran pecutan 'headform' untuk ujian hentakan tenaga tinggi (111J) sangat rapat dengan pecutan 'headform' yang sebenar (sekitar 5%), walaubagaimanapun, untuk ujian hentakan tenaga rendah (96J), perbezaannya melebihi 18%. Andaian berkadar terus telah menyebabkan model ini hanya terpakai untuk umur penggunaan sekitar 24 bulan sahaja. Sampel yang kecil (N=55) tidak membolehkan model yang jitu dibangunkan. Proses tapisan untuk kelayakan untuk diuji telah mengeluarkan maklumat penting dan perlu diberi pertimbangan untuk kajian yang akan datang.

Secara kesimpulannya, kajian ini telah membentang maklumat berguna berkaitan prestasi impak topi keledar terpakai berkaitan dengan pecutan 'headform' dan faktor-faktor berkaitan. Ia juga telah memberi maklumat awal berkaitan tempoh penyimpanan topi keledar terpakai.

Kata kunci: *Topi keledar, pecutan 'headform'*

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Thank you all for the spirited efforts.

I certify that a Thesis Examination Committee has met on 09 May 2016 to conduct the final examination of Azhar bin Hamzah on his thesis entitled "Experimental Determination of Safe Service Life of Motorcycle Helmet" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Name of Member of Supervisory Committee: Associate Professor Dr. Nawal Aswan Abdul Jalil

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LIST OF ABBREVIATIONS

FR	Frontal
HA	Headform acceleration
HM	Helmet mass
LD	Liner density
LL	Lateral left
LR	Lateral right
LT	Liner thickness
RR	Rear
SA	Service age
ST	Shell thickness

CHAPTER 1

INTRODUCTION

1.1 Background

Motorcycles have been a popular transportation mode in Malaysia for the past decades and are strongly believed to continually persist into the near future, as forecasted by the Malaysian Motorcycle Dealers Association (The Star, 2014). In the regional and global contexts, Malaysia placed second in terms of motorcycle ownership per 1000 population (Laksanakit, 2014). However, the growth in numbers has been seriously marked by a multi-fold numbers of casualties and injuries, which has been showing an upward trend particularly in terms of fatalities and consistently accounts more than 55% of total road fatalities (Sarani *et al.*, 2011). Established data indicated that the numbers have steadily exceeded 3300 deaths since 2000, in which, in most countries, injurious head trauma contributed approximately about 55-85% (Seay *et al.*, 2004). Similarly, recent findings by Ramli$_a$ (2014) indicated that 32% of the fatal motorcycle crash cases investigated showed a Maximum Abbreviated Injury Scale (MAIS) score of 5 with head injury being the most common cause of death. The Abbreviated Injury Score (AIS) is scaled from 1 to 6, in which score 5 reflected an injury status of critical and score 6 is denoted as non-survivable (AAAM, 2005) . Further away in other continent, the scenario in Nigeria reflected a similar pattern in which more than 50% of motorcyclists suffered head injuries as a result of either vehicular collisions or single vehicle crash (Yusof *et al.*, 2014). With respect to motorcycle riders and pillion passengers, Pruthi (2010) discovered there was no significant difference in terms of head injury risks to both groups, and further stressed that helmet works well to mitigate head injury risks.

Therefore, one of the injury mitigation strategy for motorcyclists is the use of certified motorcycle safety helmets. It has been proven to be effective in minimizing the injury risks especially to the motorcyclists' heads in a number of crash scenarios (Liu *et al.*, 2008; MacLeod *et al.*, 2010 and MAIDS, 2001). Proper use is also comparatively paramount in ensuring the helmets performed optimally when in needs, especially when head impacts occur. Correspondingly, it also means to incorporate, among others, standard-compliant helmets, correct size and good-fit to the wearers' heads, the retention system (chin strap) to be safely secured and preserved helmet structures and integrity. In simple terms, the helmet satisfactory structures and the integrity levels imply the helmet capability to perform as designed when the need arises, at least at par, with its certification performance when new. It was estimated that good appearance of helmet's outer shell that is without recognizable cracks and preserved liner may provide visual cue for reliable crash impact performance (Pruthi *et al.*, 2010).

In Malaysia, new helmets performance compliance is well established and stringently regulated by the road transport authorities (MS1:1996 and RTA). Randomly selected helmet samples will go through destructive mechanical tests such as impact

attenuation, penetration resistance and retention system tests, in a certified laboratory. In particular, impact attenuation test, or commonly referred to as impact test measures the helmet capability to absorb maximal crash impact energy so that the wearer's head only experience minimal contact loads and acceleration. This capability is considered a critical element of helmet protective function, if not the most critical. For certification, each batch of helmets that meet all the minimum performance criteria will be imprinted with a unique seal as sign of approval MS1:1996. The established protocols in the helmet standards ensure helmets are designed and constructed to a pre-determined performance level to optimize their operational functions. Helmets serve to protect the motorcyclists' heads including the face in the event of collision impacts. For normal motorcycle riding, helmets also provide shielding from road debris, winds, rains and also acoustic noise. However, there is a clearly insufficient information and practical advice with regards to helmet retention period.

Once helmets are used by motorcyclists on roads and after a period of exposures, concerns arise on the overall functional performance of these in-service helmets in sustaining the optimal protection to the wearers, particularly their impact performance. During use intervals, helmets are exposed and subjected to weathering factors such as ultraviolet (UV) radiation, heat, moisture and also physical shock violations such as unintentional drops. After a prolonged utilization, these variables are perceived to adversely influence helmet material properties and subsequently its impact energy absorbing and protective capabilities.

Therefore, this particular study is initiated to further understand and fill the gap in current knowledge with respect to motorcycle safety helmet crash-worthiness performance, particularly in Malaysia. Such study is vital due to the facts that motorcycle crashes in the country has been repeatedly shown dominating annual injury and fatality statistics (Figure 1.1).

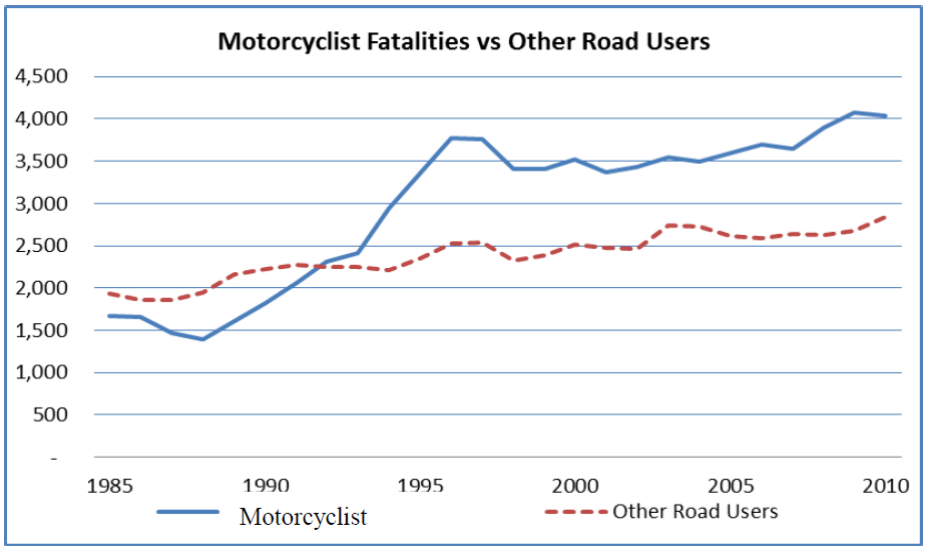

Figure 1.1 : Motorcyclist fatalities versus other road users
(Adapted from Roslan *et al.*, 2011)

To get a better understanding of the situation, the following paragraphs provide brief illustration of how prevalent it has been since the last decade and why such work may have the potential to provide leads and clues for policy makers and road authorities to diligently consider when drafting future national traffic safety direction, policies and legislations. It is essential to note that despite the numerous interventions and efforts by authorities and stakeholders, the motorcycle casualties in road traffic remains extremely high (>50%) and it is hoped that this study would be able to disclose new knowledge on motorcyclists' safety for future initiatives and intervention programs.

1.2 Problem statement

Motorcycle safety helmet studies have continually attracted countless researches and experiments, of which most of these works engrossed primarily in helmets use and effectiveness in a macroscopic perspective. In most cases they measure percentage of wearing and not wearing, survivability rate and injury severity in a motorcycle population sample, with little information describing actual helmet crashworthiness performance during impact events. Correspondingly, little distinction is made to the impact energy absorbing performance or alternately, the head acceleration values, with respect to the service ages of these helmets. In other words, in-depth investigation of used helmets (or in-service helmets) performance is rather limited. The used helmets crashworthiness studies relative factors such as service age, physical and mechanical properties were also rarely profiled. Exposures to environmental factors and stresses such as ultra-violet (UV) irradiation, moisture and heat during utilization may, to a certain extent, affect the critical protective factors of the helmets, which include the energy absorbing performance during crash impacts. Impact violations during use such as unintentional drops, if occur frequently, may also influence the shell and liner densities and their energy dispersal and compressive potentials. Such

adversity may potentially result in a relatively lower than optimal protection to the wearers, and may consequently exacerbate the head injury incidences and severities.

In brief, there are scarce information and inadequate details on used helmets crashworthiness performance relative to head acceleration records and also very vague advisory statement on the helmet retention and replacement needs (including disposal). Therefore, it is of significant importance to objectively bridge this knowledge gap and it is highly hoped that this study would be able to provide new information and findings of the used helmets crashworthiness performances by predicting the potential headform acceleration records.

1.3 Significance of study

Having such a high motorcycling population (11.5 million) in the country and with the motorcycle registration records approaching 50% of the total registered vehicles, motorcyclists' protection such as safety helmets become among the vital element for injury risks reduction control tools. Crashworthy helmets provide effective protection to the wearers' head during direct crash impact by dispersing the concentrated impact energy throughout the helmet hard shell surface and allow the inner liner to absorb the remaining loads by experiencing physical deformation. Thus, to be effective, helmets are designed to absorb most of the impact energy in order to affect a significant reduction in the head acceleration potential well below the head injury threshold limits.

The findings and outcome of this study is hoped to provide essential information to consumers, motorcyclists in particular, for their safety precaution when utilizing their motorcycles and helmets on roads. Information such as helmet crashworthiness performances, helmet estimated effective life and determinants affecting helmet performance are important for helmet users.

1.4 Thesis objectives

1.4.1 General objective

To determine used safety helmet crashworthiness performance with regards to headform acceleration performance in impact attenuation test

1.4.2 Specific objectives

i) To determine used helmet headform acceleration performance relative to service age
ii) To examine headform acceleration performance at four sides of used helmet
iii) To identify factors affecting used helmet head acceleration performance

1.5 Hypothesis

It is postulated that helmet crashworthiness performance tends to deteriorate over its service life and significantly influenced by the shell and liner performances, after prolonged utilization and exposures to environmental factors such as Ultraviolet irradiation (UV) and pre-impact factors when in use. In addition, it is expected that the outer shell will undergo significant degradation in terms of mechanical energy dissipation performance and the impact liner deteriorates in performance as a result of frequent use and pre-shock violations which may include unintentional drop of helmet from significant vertical heights, during the use tenure.

It is also postulated that helmet crashworthiness, measures in terms of head acceleration values, tends to deteriorate during its service life. In helmet certification process, the energy absorbing performance is generally measured by the headform peak resultant acceleration records (addressed simply as headform acceleration (HA)) during impact contacts. This headform acceleration is a resemblance of motorcyclist's head acceleration experience when involved in crash impacts.

For this study, the following hypotheses are tested;

1.5.1 Headform acceleration is dependent of helmet service age

1.5.2 Headform acceleration is dependent of helmet mass, liner density, liner thickness and shell thickness

1.5.3 Headform acceleration is independent of sites and impact speed

1.6 Conceptual framework

Figure 1.2 explains the whole process of the study. It starts with definition and characteristics of helmet to be collected and measured. Then performance evaluation will be conducted to identify potential and significant determinants affecting helmet head acceleration. Execution of impact tests including data measurement and collection of the dependent variable, headform acceleration are performed for all the identified helmet samples.

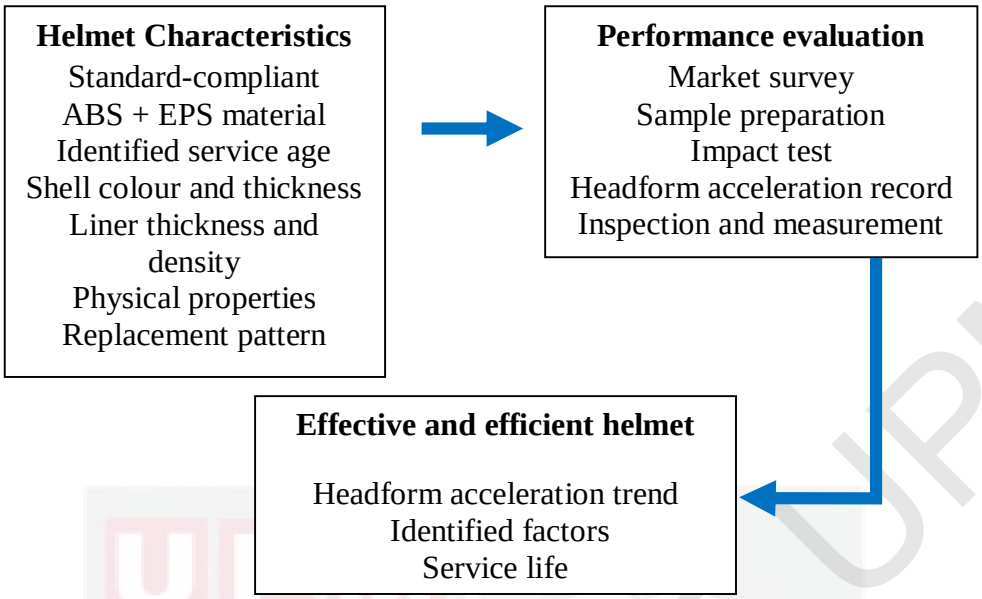

Figure 1.2 : Conceptual framework

1.7 Scope of study

This particular study involves standard-compliant motorcycle safety helmet collected randomly from the public and concerns only the open-face helmet type. Additionally, used helmets refer to helmets from public which have been used on roads and exposed to utilization and environmental factors. The performance tests were limited to headform acceleration records and excluded penetration resistance and the retention system tests. Furthermore, the test method is restricted to standard test protocols, Malaysian Standards MS1:1996 in particular, which reflected some fractional similarities to United Nations Regulations No. 22 (UN R22.05). For information, at time this report was produced, there was no request for helmet certification to the latest standard, MS1:2011, from the local helmet manufacturers.

1.8 Study limitations

The study analyses real world helmet samples for the physical test. Thus, all data pertaining to designs, materials characteristics and physical properties are subjected to common industrial practices and establish standards, in this case Malaysian Standards for motorcycle helmets, MS1:1996. In other words, the succeeding analysis and findings originated from this work is rather limited and may need further studies, if generalisation is desired.

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