Bonding Strength of Poly(vinyl acetate)-Based Adhesives in Some Wood Materials Treated with Impregnation

YALÇIN ÖRS, MUSA ATAR, AYHAN ÖZÇİFÇİ

Gazi University, Technical Education Faculty, 06 500 Ankara, Turkey

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ABSTRACT: This experimental study was carried out to determine the bonding strength of poly(vinyl acetate)-based (PVAc) adhesives [i.e., Klebit 303 (K_{303}), Kleiberit 305.0 ($K_{305.0}$), and Super Lackleim 308 (SL_{308})] for some impregnated wood materials used in woodworking industries. For this purpose, Oriental beech (*Fagus orientalis lipsky*), Uludağ fir (*Abies bormülleriana mattf.*), and Scotch pine (*Pinus sylvestris lipsky*) woods were impregnated with tanalith-CBC (T-CBC) and imersol-WR 2000 (I-WR 2000) by dipping and vacuum method according to the procedure of ASTM-D 1413-76 standards. The shear strength test was conducted on the connection surface of samples jointed by four different adhesives. The test results showed that the highest shear strength (11.84 N/mm^2) was obtained for the wood materials of Oriental beech treated by T-CBC with K_{303} by using the dipping method. The lowest shear strength (3.1 N/mm^2) was obtained for Scotch pine treated by T-CBC with $K_{305.0}$ by using the vacuum method. © 2000 John Wiley & Sons, Inc. J Appl Polym Sci 76: 1472–1479, 2000

INTRODUCTION

The furniture-manufacturing industry has changed technically and structurally by the development of synthetic resins. For example, synthetic resin joints are used in the production of cabin and wooden furniture instead of the mechanical joints such as nails and screws.

Today, synthetic resins are produced according to wood materials used on dry and humid conditions. They are also convenient to use in the workshop and continuous manufacturing. To prevent material scraps and to increase the quality, researchers have continued the development of glue and its new application areas.[1]

Unless the wood materials are covered with protective chemical substances, they can be damaged by funguses, insects, fire, and humidity. As a result of this, before the economic life ends, the wood materials may need to be repaired and renewed.[2] For this reason, wood materials must be impregnated by protective chemical substances before use.[3]

It was reported that when Scotch pine woods (*Pinus sylvestris lipsky*) are jointed with Desmodur–VTKA adhesive and tanalith-CBC (T-CBC) by using full-cell methods, the hold resistance decreases.[4]

It was observed that the joints of Oriental beech (*Fagus orientalis lipsky*), Scotch pine, and oak (*Quercus petraea spp.*), which are glued by Desmodur–VTKA, have no change in tension and shear resistance after the climatization process, holding in cold, hot, and boiling water. Therefore, this glue can be used in dry and humid conditions.[5]

Butt, tongue–groove, and edge-to-edge butt 45°-angled joints were made by using 19-mm thickness particleboard and glued by ureaformaldehyde (UF) and poly(vinyl acetate) (PVAc) adhesives. The highest shear resistance (16.1 N/mm^2) was determined in tongue and groove joints with UF adhesive; 12.2 N/mm^2 resistance value for

Correspondence to: Y. Örs.

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edge-to-edge butt 45°-angled joint and 10.6 N/mm^2 for unprocessed joints were found.[6]

Phenol resin, which can be solidified in cold, was modified by cellulose, flour of glass, wood bark, and ceramic, and then used for jointing of wood to wood, and particleboard to wood materials. It was observed that a modified adhesive has less resistance compared with a pure adhesive.[7]

The wood of the Oriental beech, oak, and Scotch pine were jointed to the edge of particleboard and medium density fiberboard (MDF) were jointed by Desmodur–VTKA adhesive; then their tensile strength was measured. The highest shear resistance (4.403 N/mm^2) was obtained for the cross section of Oriental beech and the 5.818-N/mm^2 section for edges of MDF covered with wood material.[8]

The aim of this experimental study is to determine the bonding resistance of the woods of Oriental beech, Scotch pine, and Uludağ fir (*Abies bormülleriana mattf.*), which were impregnated and used widely in a furniture production, glued by PVAc, Klebit 303 (Klebchemie, M. G. Becker GmbH-Co. KG, Baden, Germany), Kleiberit 305.0 (Klebchemie, M. G. Becker GmbH-Co. KG), and Super Lackleim 308 (Klebchemie, M. G. Becker GmbH-Co. KG).

EXPERIMENTAL

Wood Materials

The woods of Oriental beech, Scotch pine, and Uludağ fir were chosen randomly from timber merchants of Ankara, Turkey.

Adhesives

Four different adhesives (each containing one component and not containing solvent) were used. These adhesives are usually preferable for the assembly process in the furniture industry.

The following adhesives were used in this experiment. PVAc is a odorless, nonflammable adhesive. It can be used in cold temperatures and solidifies quickly. Its application is very easy and does not damage the tools during the cutting process. However, PVAc adhesive's mechanical resistance decreases with increasing heat. It loses bonding resistance capacity over 70°C. On the condition that the adhesive is applied to only one surface, the use of 150–200 g/m^2 adhesive seems to be suitable.[9]

TS 3891 standard procedure was used for applying PVAc adhesive. The density of PVAc should be 1.1 g/cm^3, and the viscosity should be 16.000 ± 3.000 mPa s; pH value and ash ratio should be 5 and 3%, respectively. A pressing time of 20 min for cold process and 2 min at 80°C are recommended with 6–15% humidity for jointing process. After a hot-pressing process, the materials should be held until its normal temperature is reached.[10] PVAc adhesive was supplied from Polisan, a producer firm in İzmit, Turkey.

PVAc-based adhesives, K_{303}, $K_{305.0}$, and SL_{308}, were supplied from the producer firm Klebchemie, M. G. GmbH-Co. KG Germany in packing viscosity.

K_{303} can be applied cold or hot according to the directions of the manufacturer. Its density is 1.22 ± 0.01 g/cm^3; pH value is 7, and viscosity is 13.000 ± 2.000 mPa s at 20°C and 65% relative humidity. It solidifies in 20 min. For a good connection, 120–200 g/m^2 adhesive and 6–10 min holding time is recommended.[11]

$K_{305.0}$ can be applied cold and hot. Its density is 1.20 g/cm^3; pH is approximately 7, and viscosity is 13.000 ± 2.000 mPa s at 20°C. At 20°C and 65% relative humidity, it solidifies in 20 min. It is elastic, and resists humidity, and can be applied by hand. It is recommended that 150–200 g/m^2 of $K_{305.0}$ be applied to both surfaces and held for about 10 min.[11]

SL_{308} has a pH of about 7.5 and a viscosity of 12.000 ± 3.000 mPa s at 20°C. Its density is 106 g/cm^3; the period of solidification at 20°C with 65% relative humidity is 6–8 min. Exact solidification occurs within 2–3 h. It is recommended that 150–200 g/m^2 of SL_{308} be applied to both surfaces.[11]

Impregnation Materials

I-WR 2000 and T-CBC, used in the impregnation process, were supplied from Polisan in İzmit, Turkey. I-WR 2000, one of the organic solvent impregnation substrates, is served to the market. It is appropriate for the procedure of BS 5707 class I F2/NI and BS 5268 standards. It does not create corrosion on the metal surfaces. The dipping period changes between 5 to 10 min. After the impregnation process, it can be glued immediately and held 2 days for finishing.

Bore compounds were chosen for the experiment because they can be easily found in the market, are not flammable, and are inexpensive. To prevent bore compounds from washing away

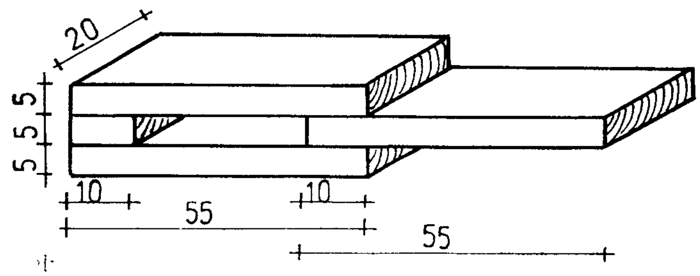

Figure 1 The test sample (sizes given in mm).

from the woods, a water repellent that prevents shrinkage and swelling of wood was used.[12]

T-CBC contains 88% $Na_2Cr_2O_7$ $2H_2O$, 37.5% $CuSO_4$ $5H_2O$, and 24% H_3BO_3. T-CBC is a bore impregnation chemical and can be prepared by using bore minerals instead of arsenic salt, which is CCA salt-type.[13]

Preparation of Experimental Samples

The wood samples cut from sap wood were conditioned at 20 ± 2°C and at 65 ± 3% relative humidity until their weights became stable by holding them 3 months in the conditional room. Cut were 112 test samples with 12% average moisture to dimensions according to the procedure of TS 5430 for each wood species.[14]

To prepare test samples (55 × 20 × 10 mm), the impregnation process was applied according to the procedure of ASTM-D 1413-76 standards. For that, 60 cm Hg^{-1} prevacuum was applied to the samples for 60 min and then they were held in solution under normal atmospheric pressure for 60 min.[15] Similar to the dipping method, according to TS 344, the samples were held 5 days in an impregnation solution.[16] The peculiarities of impregnation were determined before and after the impregnation process. All processes were carried out at 25 ± 5°C. The samples, oven dried before and after impregnation, can be calculated by the formula,[17]

$$R = \frac{G \times C}{V} \times 10^3 \text{ [kg/m}^3\text{]} \quad (1)$$

where R is the retention of impregnation material, $G = T_2 - T_1$, T_1 is the sample weight before impregnation [g], T_2 is the sample weight after impregnation [g], C is the concentration [%], and V is the volume of the samples [cm^3].

Impregnated test samples were kept at 20 ± 2°C and at 65 ± 3% relative humidity until their weights became stable. After applying approximately 150–200 g/m^2 of glue to the surface, the samples were held under 0.2 N/mm^2 pressure for 30 min as shown in Figure 1. Prepared test samples were conditioned at 20 ± 2°C and at 65 ± 3% relative humidity.

Application of Experiment

The test of shear strength was carried out according to the procedure of EN 205 standards.[18] The loading speed was 50 mm/min (Fig. 2).

The loading was continued until a break or separation occurred on the surface of the test samples; meanwhile, observing load (F_{max}), bonding surface of sample (A, in mm^2), and shear strength (σ_k) were calculated as follows:

$$\sigma_k = \frac{F_{max}}{2A} = \frac{F_{max}}{2(a \times b)} \text{ N/mm}^2 \quad (2)$$

where a is the width of glued face (10 mm), and b is the length of glued face (20 mm).

Data Analyses

By using four different types of glue, two impregnation materials, two impregnation methods, and three kinds of wood as parameters, a total of 336

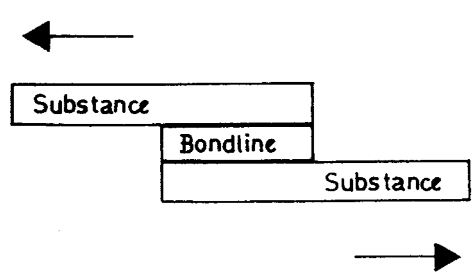

Figure 2 Tensile experiment apparatus.

Table I Peculiarities of Impregnation Solutions

Experiment No.	Impregnation Materials	Solution Material	Viscosity (Sn/ Din Cup/4 mm at 20°C)	Solution Concentration (%)	pH		Density		Temp. (°C)	
					B.I.	A.I.	B.I.	A.I.	B.I.	A.I.
1	T-CBC	pw	13	13	2.50	2.48	1.08	1.08	23	23
2	I-WR 2000	100%	9	100	3.00	3.00	0.81	0.81	23	23

pw, pure water; B.I., before impregnation; A.I., after impregnation.

samples (4 × 2 × 2 × 3 × 7) were prepared, with seven samples for each parameter.

Multiple variance analysis was performed to determine the differences between the bonding strengths of the jointing surfaces of the prepared samples. It was determined by Duncan test that there is a meaningful difference between the groups.

RESULTS AND DISCUSSION

Peculiarities of Impregnation Solutions

Peculiarities of impregnation solutions used in the impregnation of test samples are given in Table I. It can be seen in Table I that there is no change in pH and density of the solution before and after the impregnation. This may be attributed to the use of fresh solution in every impregnation process.

Amount of Retention

The amount of retention of impregnation materials used in the experiments according to the impregnation method and species of wood are given in Table II. The highest retention value was observed for T-CBC with the vacuum method on fir and the lowest on Scotch pine. By using the dipping method, the highest value was obtained on Scotch pine and the lowest value on fir. Using I-WR 2000, the highest retention was recorded on Scotch pine and the lowest value on Oriental beech with both methods.

When using T-CBC, the retention value may be affected by the rate of cell pore with vacuum method and by permeability with the dipping method. These effects can be obviously seen for fir. This may be because of the aspirated bordered pits (of fir). The retention value for I-WR 2000 may be affected by cell-pore rate and permeability with both methods.

Shear Strength

The average values of shear strength obtained for different species of wood materials are given in Table III. The average values of shear strength and interaction for wood material + impregnation material and impregnation method + adhesives are given in Table IV. The results of multiple analyses in regard to the effects of wood species, impregnation material, the impregnation method, and type of adhesives are given in Table V.

Table II The Retention Amount of Scotch Pine, Oriental Beech, and Fir (kg/m^3)

Impregnation Method	Vacuum				Dipping			
Impregnation Material	T-CBC		I-WR 2000		T-CBC		I-WR 2000	
Wood Material	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Scotch Pine	30.16	1.27	223.48	2.25	23.44	2.71	138	2.11
Uludağ Fir	44.22	1.50	170.36	1.75	10.25	2.90	92	1.85
Oriental Beech	41.08	2.20	123.54	2.25	10.92	3.25	72	2.78

$\bar{X}$, average; S, standard definition of estimate.

Table III Average Shear Strengths According to the Type of Material

Types of Material	σ_k (N/mm^2)	HG
Wood materials		
I	6.98	A
II	4.77	B
III	4.63	B
Adhesives		
PVAc	5.62	B
K_{303}	6.42	A
$K_{305.0}$	4.81	D
SL_{308}	4.99	C
Impregnation materials		
T-CBC	6.08	A
I-WR 2000	4.84	B
Impregnation method		
D	6.26	A
V	4.66	B

I, beech; II, Scotch pine; III, fir; D, dipping; V, vacuum; HG, degree of homogen.

The highest value of shear strength was found for beech-wood materials, K_{303} in the adhesives, T-CBC in the impregnation substances and dipping method. This may be because that beech wood has the higher density and K_{303} adhesive gives a stronger adhesion on the wood surface. The lower retention for impregnation using the T-CBC with dipping method may be attributed to the fact that the amount of impregnation substance could have a negative effect, decreasing the shear strength of the wood material.

It can be said that decreasing the retention for impregnation with T-CBC by using the dipping method will increase the shear strength and form a better connection between K_{303} adhesive and the wood material. Beech wood has higher shear strength due to its higher density its small trahe. So it is proven from those results of twin interaction.

The difference between groups regarding the effect of variance sources on shear strength has been meaningful (5%). Duncan test results conducted to determine the importance of differences between the groups are given in Table VI.

According to the Duncan test results, T-CBC and K_{303} adhesive with the dipping method gave the highest shear strength values for each kind of wood. Impregnation with vacuum method increases the amount of retention. In the case of increasing impregnation substance, the adhesion between the wood and the adhesive may decrease.

The shear strengths according to the impregnation method and adhesive type are shown in Figure 3.

CONCLUSIONS

Amounts of retention for I-WR 2000 were higher than T-CBC according to the impregnation process by the dipping and vacuum method with beech, Scotch pine, and fir.

The results showed that when the impregnation process is worked out for I-WR 2000 by using the dipping method, the retention is higher than the one for T-CBC by using the vacuum method. Therefore, in an impregnation process with I-WR 2000, the use of a dipping method may be sufficient.

Table IV Averages of Shear Strength According to the Interaction of Wood Material, Impregnation Substance, and Impregnation Method (N/mm^2)

Wood and Impregnation Material	Impregnation Method and Adhesives							
	Vacuum				Dipping			
	PVAc	K_{303}	$K_{305.0}$	SL_{308}	PVAc	K_{303}	$K_{305.0}$	SL_{308}
I + I-WR 2000	3.81	5.19	4.98	3.01	7.13	8.07	7.21	4.69
I + T-CBC	8.15	10.02	4.55	7.08	10.28	11.84	7.25	8.46
II + I-WR 2000	3.87	4.41	4.01	3.14	5.78	5.99	5.26	5.44
II + T-CBC	4.36	4.55	3.10	4.52	4.99	6.08	4.72	6.07
III + I-WR 2000	4.07	4.52	3.81	3.12	4.80	4.88	5.21	4.57
III + T-CBC	4.45	5.48	3.26	5.13	5.78	5.95	4.37	5.44

See Table III for definitions.

Table V The Results of Multiple Variance Analyses of Glue Types, Wood Species, Impregnation Chemical, and Method

Source	Degrees of Freedom	Sum of Square	Means of Square	*F* Value	Probability 5%
İnt.-A	2	391.476	195.738	1659.117	0.0000
İnt.-B	1	129.096	129.096	1094.249	0.0000
AB	2	127.918	63.959	542.132	0.0000
İnt-C	1	216.242	216.942	1832.912	0.0000
AC	2	22.896	11.448	97.035	0.0000
BC	1	4.125	4.125	34.966	0.0000
ABC	2	0.070	0.035	0.296	—
İnt-D	3	132.948	44.316	375.631	0.0000
AD	6	58.349	9.725	82.430	0.0000
BD	3	95.623	31.874	270.174	0.0000
ABD	6	31.805	5.301	44.93	0.0000
CD	3	0.950	0.317	2.68	0.0470
ACD	6	9.637	1.606	13.61	0.0000
BCD	3	3.929	1.310	11.10	0.0000
ABCD	6	8.392	1.399	11.85	0.0000
Error	288	33.977	0.118	—	—

İnt.-A, material; İnt.-B, impregnation; İnt.-C, method; İnt.-D, adhesive.

Table VI The Results of Duncan Test (N/mm^2)

Wood and Impregnation Materials and Methods, and Adhesive	$\bar{X}$	HG	Wood and Impregnation Materials and Methods, and Adhesive	$\bar{X}$	HG
I + T-CBC + D + K_{303}	11.840	A	I + I-WR 2000 + V + $K_{305.0}$	4.970	OP
I + T-CBC + D + PVAc	10.280	B	III + I-WR 2000 + D + K_{303}	4.880	PQ
I + T-CBC + V + K_{303}	10.020	C	III + I-WR 2000 + D + PVAc	4.790	QR
I + T-CBC + D + SL_{308}	8.464	D	II + T-CBC + D + $K_{305.0}$	4.720	RS
I + T-CBC + V + PVAc	8.140	E	I + I-WR 2000 + D + SL_{308}	4.690	S
I + I-WR 2000 + D + K_{303}	8.070	E	III + I-WR 2000 + D + SL_{308}	4.560	T
I + T-CBC + D + $K_{305.0}$	7.250	F	I + T-CBC + V + $K_{305.0}$	4.550	T
I + I-WR 2000 + D + $K_{305.0}$	7.210	FG	II + T-CBC + V + K_{303}	4.550	T
I + I-WR 2000 + D + PVAc	7.120	GH	II + T-CBC + V + SL_{308}	4.520	TU
I + T-CBC + V + SL_{308}	7.080	H	III + I-WR 2000 + V + K_{303}	4.510	TU
II + T-CBC + D + K_{303}	6.086	I	III + T-CBC + V + PVAc	4.440	UV
II + T-CBC + D + SL_{308}	6.060	I	II + I-WR 2000 + V + K_{303}	4.410	V
II + I-WR 2000 + D + K_{303}	5.990	IJ	III + T-CBC + D + $K_{305.0}$	4.370	V
III + T-CBC + D + K_{303}	5.950	J	II + T-CBC + V + PVAc	4.360	V
II + I-WR 2000 + D + PVAc	5.780	K	III + I-WR 2000 + V + PVAc	4.070	W
III + T-CBC + D + PVAc	5.780	K	II + I-WR 2000 + V + $K_{305.0}$	4.000	W
III + T-CBC + V + K_{303}	5.482	L	II + I-WR 2000 + V + PVAc	3.860	X
III + T-CBC + D + SL_{308}	5.442	L	I + I-WR 2000 + V + PVAc	3.810	X
II + I-WR 2000 + D + SL_{308}	5.430	L	III + I-WR 2000 + V + $K_{305.0}$	3.810	X
II + I-WR 2000 + D + $K_{305.0}$	5.251	M	III + T-CBC + V + $K_{305.0}$	3.250	Y
III + I-WR 2000 + D + $K_{305.0}$	5.207	MN	II + T-CBC + V + $K_{305.0}$	3.130	Z
I + I-WR 2000 + V + K_{303}	5.186	MN	I + I-WR 2000 + V + SL_{308}	3.120	Z
III + T-CBC + V + SL_{308}	5.136	N	III + I-WR 2000 + V + SL_{308}	3.110	Z
II + T-CBC + D + PVAc	4.980	O	II + I-WR 2000 + V + SL_{308}	3.100	Z

See Table III for definitions.

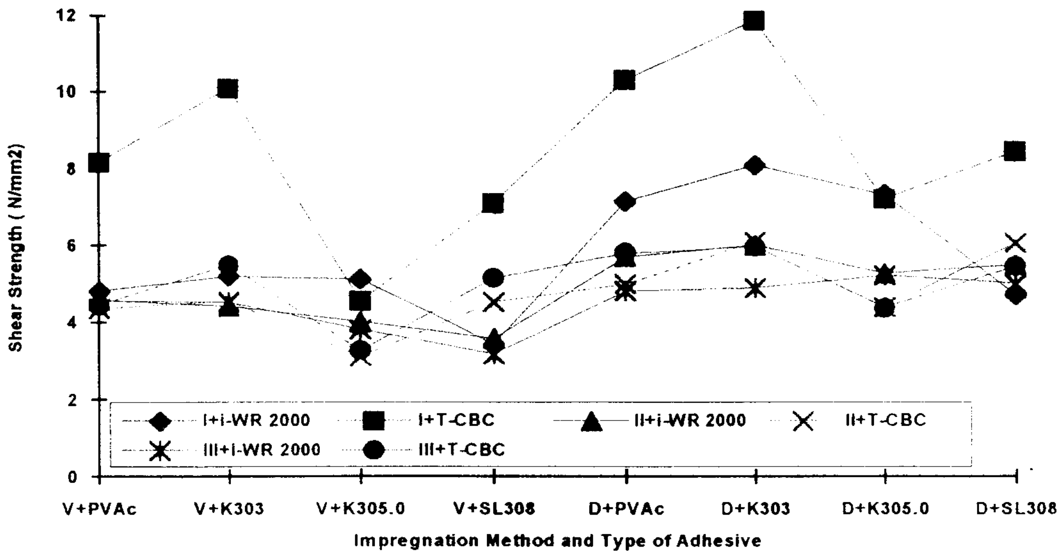

Figure 3 Shear strength according to the impregnation method and adhesive types.

The vacuum method for impregnation with T-CBC may be preferable so that there is a considerable difference of shear strengths between the beech and fir when impregnated with T-CBC.

After impregnation, the sample shear strengths were determined on the joints connected by four different adhesives. The highest shear strength was observed for beech-wood material and K_{303} adhesives. Ranked from the highest to the lowest values of shear strengths are beech, Scotch pine, and fir as materials and K_{303}, PVAc, SL_{308}, $K_{305.0}$ as adhesives, respectively.

Among the wood materials, the one impregnated with T-CBC dipping method gave the highest shear strength. In this respect, it may be concluded that while the retention of impregnation materials is increased, the shear strength is decreased. It was confirmed that the retention values for the dipping method are higher than the values for the vacuum method. Similarly, the retention values are relatively higher for T-CBC compared with I-WR 2000. It was reported that in the same experimental study of the impregnation process with T-CBC, when impregnation materials are increased, shear strengths are decreased.[4]

The highest shear strength (11.839 N/mm^2) was obtained with beech + T-CBC and dipping + K_{303} interactions. The lowest value (3.1 N/mm^2) was determined for the Scotch pine + T-CBC and vacuum method. From these results, interactions between the parameters (method, materials, adhesives) were found meaningful.

As a result, from the shear strength point of view, it is advised that T-CBC as an impregnation material, dipping as an impregnation method, and K_{303} as an adhesive for furniture elements should be manufactured after impregnation. Then these elements can be jointed with K_{303} adhesive.

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