Ruthenium-Catalyzed Addition of Aromatic Esters at the *ortho* C-H Bonds to Olefins

Motohiro Sonoda, Fumitoshi Kakiuchi, Asayuki Kamatani, Naoto Chatani, and Shinji Murai*
Department of Applied Chemistry, Faculty of Engineering, Osaka University, Suita, Osaka 565

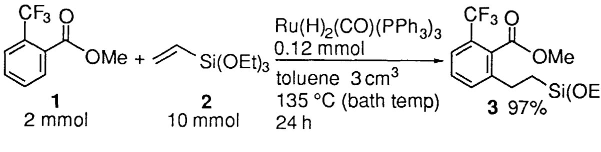
(Received October 18, 1995)

A ruthenium complex, $Ru(H)_2(CO)(PPh_3)_3$, can catalyze the addition of aromatic and heteroaromatic esters at the *ortho* carbon-hydrogen bonds to olefinic double bonds. While un-substituted alkyl benzoate did not react, those substituted with CF_3 or F underwent smooth catalytic addition. A heteroaromatic ester and a benzo-δ-lactone also reacted.

Since we reported efficient methods for cleavage and addition of sp^2 carbon-hydrogen bonds in unsaturated ketones to olefins[1-6] and acetylenes[7] using ruthenium complexes as the catalysts, the use of a carbon-hydrogen bond for synthesis has become a focus of intensive research activity.[8] During the course of our ongoing research program centered on ruthenium-catalyzed C-H/olefin coupling reactions, we have now found that aromatic and heteroaromatic esters are also applicable to the ruthenium catalyzed C-H/olefin coupling reaction. Here we disclose the results of the addition of aromatic and heteroaromatic esters to olefins.

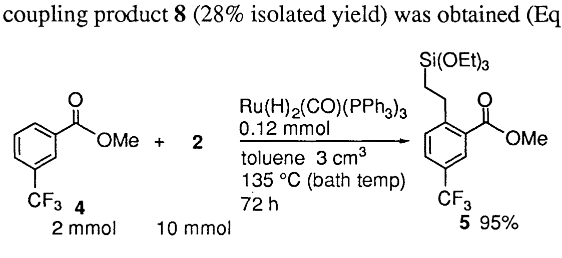
To begin with, we carried out reaction of methyl benzoate with triethoxyvinylsilane in the presence of a catalytic amount of $Ru(H)_2(CO)(PPh_3)_3$ (6 mol%), however the desired coupling reaction did not take place. Other aromatic esters, e.g., $C_6H_5CO_2Bu^t$, $C_6H_5CO_2CH_2CF_3$, $C_6H_5CO_2Ph$, *o*-$MeC_6H_4CO_2Me$, *p*-$MeC_6H_4CO_2Me$, and *p*-$MeOC_6H_4CO_2Me$ also did not give any coupling products.

We were pleased to observe, however, that the reaction of methyl 2-trifluoromethylbenzoate (**1**) with triethoxyvinylsilane (**2**) occurred smoothly to give 1:1 coupling product **3** in 97% GC yield[9] under the reaction conditions depicted in Eq. 1.[10] The ^1H NMR spectrum of **3** showed that carbon-carbon bond formation had occurred exclusively to the position ortho to the ester group as in the case of aromatic ketones[1-4] and aromatic imines.[6]

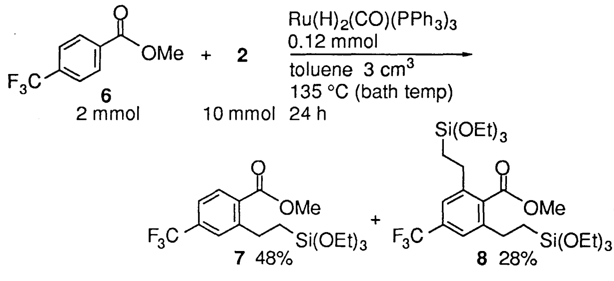


(1)

Methyl 3-trifluoromethylbenzoate (**4**) reacted with **2** to give the corresponding coupling product **5** in 95% GC yield as the sole product (Eq. 2). The carbon-carbon bond formation took place at the less congested position (6 position) with complete selectivity, and no positional isomer (i.e. at the 2 position) was detected. In the case of methyl 4-trifluoromethylbenzoate (**6**), a mixture of 1:1 coupling product **7** (48% GC yield) and 1:2 coupling product **8** (28% isolated yield) was obtained (Eq. 3).

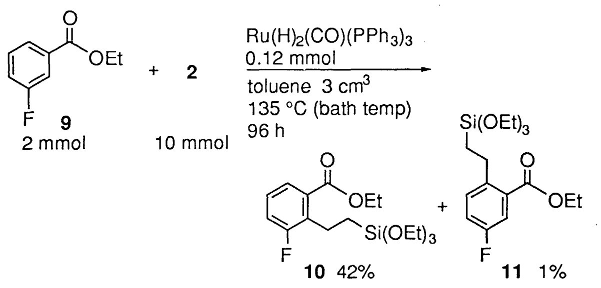


(2)

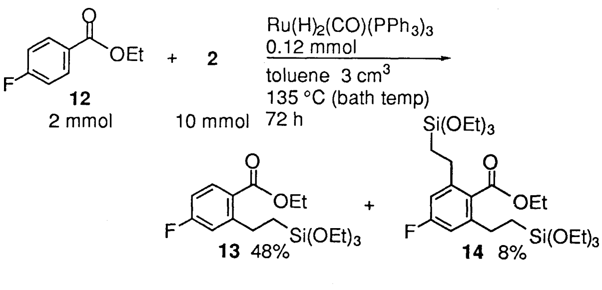


(3)

Similarly, the reaction of ethyl 3-fluorobenzoate (**9**) with **2** gave the coupling products **10** (42% GC yield) predominantly along with a small amount (1% GC yield) of the isomer **11** (Eq. 4). In this case the carbon-carbon bond is formed at 2 position and contrasts to that observed in the case of **4** (Eq. 2). The site selectivity of these reactions may be attributable to both steric factors and the electronic properties of the substituents.[11] The unshared electron pairs on the fluorine in **9** may have a weak interaction with the ruthenium directing it to the adjacent position. Ethyl 4-fluorobenzoate (**12**) also reacted to give a mixture of 1:1 coupling product **13** (48% GC yield) and 1:2 coupling product **14** (8% GC yield) (Eq.5).



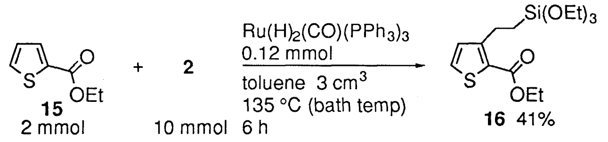
(4)



(5)

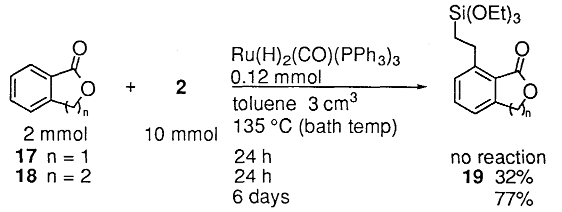
We examined the reactions of other benzoates having electron-withdrawing groups, such as *o*-CO_2Me, *o*-CN, *o*-NO_2, and, *p*-NO_2, but no coupling product was obtained at all. The role of the CF_3 and F groups in the catalytic C-H/olefin coupling reaction is not clear at the present time.[12]

Ethyl 2-thiophenecarboxylate (**15**) also underwent coupling with **2** to afford the corresponding coupling product **16** in moderate yield (Eq. 6). The reaction with methyl 2-furan-carboxylate also took place but gave a complicated mixture of products.

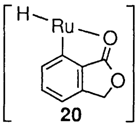


(6)

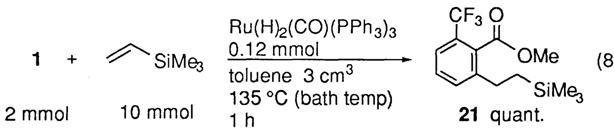
The coupling reaction of five-membered lactone **17** with **2** did not proceed at all. In contrast, six-membered lactone **18** reacted with **2** slowly to give **19** in 77% GC yield (Eq. 7). A similar reactivity dependence on the ring size has been observed in the reaction of aromatic ketones, where indanone, a five-membered ketone, did not react with **2** but a six-membered ketone, α-tetralone, did. This may be attributed to the instability of the postulated strained cyclometalated intermediate **20**.[1,3,4]



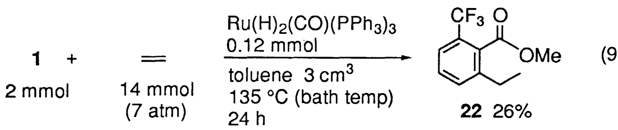
(7)


20

The reaction of **1** with trimethylvinylsilane gave **21** in quantitative yield (Eq. 8). In the case of the reaction with ethylene, **22** was obtained in 26% GC yield (Eq. 9). Other olefins such as allyltrimethylsilane, 1-hexene, and styrene were unreactive in the present reaction, indicating a different reactivity pattern from that observed in the reaction of aromatic ketones.[1,3,4]



(8)



(9)

In summary, a novel ruthenium catalyzed addition of the *ortho* carbon-hydrogen bonds of aromatic and heteroaromatic esters to olefinic double bonds has been demonstrated. The reaction, in addition to our previous work,[1-7] offers an entirely new methodology for aromatic substitution. Further studies are underway to explore mechanistic factors including the role of the CF_3 and F groups, as well as further applications of the chelation-assisted C-H/olefin coupling reaction to other catalytic systems.[7] During the course of the present work, Trost and co-workers reported[8d] a similar catalytic reaction of α, β-unsaturated acid esters. We are also studying this reaction and the results will be reported in due course. A formally similar catalytic dimerization of acrylic esters has also been reported[13] but this reaction seems to proceed by a different mechanism.

Supporting Information Available (6 pages) including spectral data of new compounds are available on request to the author by telefax (+81-6-879-7396).

References and Notes

1 S. Murai, F. Kakiuchi, S. Sekine, Y. Tanaka, A. Kamatani, M. Sonoda, and N. Chatani, *Nature (London)*, **366**, 529 (1993).

2 S. Murai, F. Kakiuchi, S. Sekine, Y. Tanaka, A. Kamatani, M. Sonoda, and N. Chatani, *Pure Appl. Chem.*, **66**, 1527 (1994).

3 S. Murai, *J. Synth. Org. Chem., Jpn.*, **52**, 992 (1994).

4 F. Kakiuchi, S. Sekine, Y. Tanaka, A. Kamatani, M. Sonoda, N. Chatani, and S. Murai, *Bull. Chem. Soc. Jpn.*, **68**, 62 (1995).

5 F. Kakiuchi, Y. Tanaka, T. Sato, N. Chatani, and S. Murai, *Chem. Lett.*, **1995**, 679.

6 F. Kakiuchi, Y. Yamauchi, N. Chatani, and S. Murai, *Chem. Lett.*, in press (accompanying paper).

7 F. Kakiuchi, Y. Yamamoto, N. Chatani, and S. Murai, *Chem. Lett.*, **1995**, 681.

8 a) Y.-G. Lim, Y. H. Kim, and J.-B. Kang, *J. Chem. Soc., Chem. Commun.*, **1994**, 2267; b) H. Guo and W. P. Weber, *Polymer Bull.*, **32**, 525 (1994); c) H. Guo, M. A. Tapsak, and W. P. Weber, *Polymer Bull.*, **33**, 417 (1994); d) B. M. Trost, K. Imi, and I. W. Davies, *J. Am. Chem. Soc.*, **117**, 5371 (1995); e) N. A. Williams, Y. Uchimaru, and M. Tanaka, *J. Chem. Soc., Chem. Commun.*, **1995**, 1129.

9 The yields were determined by GC unless otherwise noted.

10 Compounds were identified on the basis of their ^{1}H NMR, ^{13}C NMR, IR and mass spectral characteristics (see supporting information available). Representative experi-mental procedure: a mixture of an aromatic ester (2 mmol), **2** (10 mmol) and $Ru(H)_2(CO)(PPh_3)_3$ (0.12 mmol) in toluene (3 cm^3) was vigorously refluxed (oil bath temperature, 135 °C) with stirring. After heating for 24 hours, the mixture was allowed to cool to room temperature, and toluene and **2** were removed by rotary evaporation. The product was isolated by bulb-to-bulb distillation (170 °C/2 mmHg) in 97% yield. The GC yield was determined by a separate run under the same reaction conditions except for addition of hexadecane as an internal standard for GC.

11 M. Sonoda, F. Kakiuchi, N. Chatani, and S. Murai, *J. Organomet. Chem.*, in press.

12 The σ-electron withdrawing group can accelerate either the C-H cleavage step or the reductive elimination step.

13 The Rh-catalyzed dimerization of methyl acrylate seems to proceed via a hydrometallation-carbometallation-dehydrometallation mechanism, see: a) M. Brookhart and S. Sabo-Etienne, *J. Am. Chem. Soc.*, **113**, 2777 (1991); b) M. Brookhart and E. Hauptman, *J. Am. Chem. Soc.*, **114**, 4437 (1992); c) E. Hauptman, S. Sabo-Etienne, P. S. White, M. Brookhart, J. M. Garner, P. J. Fagan, and J. C. Calabrese, *J. Am. Chem. Soc.*, **116**, 8038 (1994).