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Heck reaction on fullerene derivatives

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Abstract

The Heck reaction on fullerene-based aryl iodides has been achieved for the first time in good yields by using microwave irradiation.

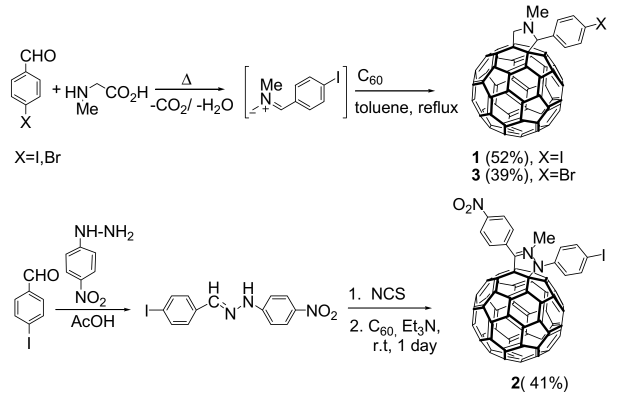
Keywords: Fullerene; Heck reaction; Microwave

The palladium-catalyzed Heck reaction of olefins with *aryl* and *vinyl* halides is actually a method of broad scope that has found application throughout organic chemistry mainly due to its high chemoselectivity and mild reaction conditions.[1] Particularly interesting is the iterative use of the Heck reaction for the construction of oligomers of *p*-phenylenevinylenes (OPVs),[2] compounds of great interests in materials research such as organic light-emitting displays (OLEDs),[3] field-effect transistors (FETs)[4] and organic solar cells.[5]

Despite the fact that a great deal of attention has been devoted in recent years to the direct functionalization of the fullerene cage, examples of reactions in proximity to the fullerene surface are scarce[6] and some functional groups have proven to be unreactive in proximity to the C_{60} cage,[7] probably due to the size of the fullerene which sterically hinders the approach of the reaction components. In particular, examples of Pd-catalyzed coupling reactions in fullerene derivatives are almost absent from the literature and only two results on Sonogashira coupling in compounds containing fullerenes have been previously reported.[8,9] This observation is probably due to the fact that low-valent complexes of palladium easily undergo complexation[10] with fullerenes; in this respect, a stable palladium complex between C_{60} and palladium acetate has been described;[11] in this sense, fullerenes can be considered a poison for palladium catalysts. As a consequence, only one example of the application of the Heck reaction on a fullerene derivative is known,[12] but the described yield is very low (10%).

In this Letter, we report a procedure to perform the Heck reaction on fullerene derivatives with good yields. This procedure is based on the use of microwave irradiation as a source of energy[13] which has shown to be very effective in coupling reactions[14] as well as in fullerene chemistry.[15]

The starting fullerene derivatives **1**–**3** were prepared in good yields (39–52%) according to the standard



Scheme 1.

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procedures, by 1,3-dipolar cycloadditions of C_{60} and azomethine ylides[16,12] (**1** and **3**) or a nitrile imine[17] (**2**) (Scheme 1).

We subsequently aimed to study the Heck coupling between the fullerene-based aryl halides (**1**–**3**) and different acrylates **4a**–**d**. Following the optimization studies, the reactions were carried out with palladium acetate as the catalyst, tri-*o*-tolylphosphine as the ligand and triethylamine as the base. The lack of solubility of fullerene in polar solvents meant that 1,2-dichloroethane and chlorobenzene were chosen instead of the classical solvents employed for this kind of reactions (e.g., DMF, NMP) (Scheme 2).

Initially, the reaction was studied under classical heating in refluxing chlorobenzene and **1** was converted into **5a** in 15% yield after 6 h (massive polymerization of the starting butyl acrylate was observed and starting compound **1** was consumed); **2** afforded **6b** in 20% yield under the same reaction conditions with acrylate **4b**. These low yields move us to study the reaction by using microwave irradiation as a source of energy.

Irradiation experiments were conduced in chlorobenzene as solvent; the temperature was kept below 140 °C in order to prevent (although not avoid) polymerization of the acrylates[18] and irradiation at 300 W was maintained until the initial fullerene derivative **1** was consumed (followed by TLC). The same experimental conditions were used in the rest of the examples and the preparative results are summarized in Table 1.

Pyrrolidino[60] fullerene-based aryl iodide **1** was converted into the corresponding cinnamic esters **5a**–**d**[19] in 34–52% yields by reaction with acrylates **4a**–**d** (reaction time: 4.5 h at 300 W). Significant differences in yields were not observed between fullerene-based aryl iodides and pyrazolino[60] fullerene **2** was converted into **6a**–**b** in 41% and 42%, respectively, under analogous conditions in a shorter reaction time (3 h).

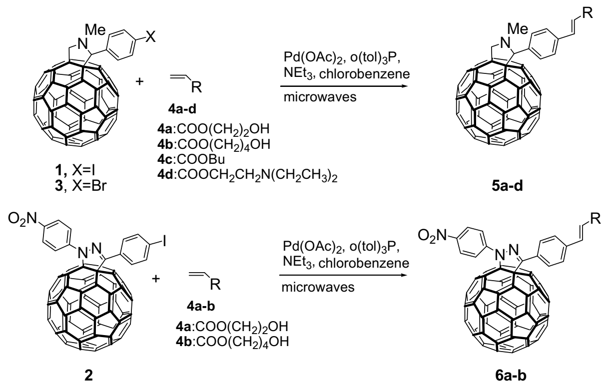
The structures of all new compounds were fully supported by FTIR, ^{1}H and ^{13}C NMR spectroscopies. The regioselectivity of the addition led in all cases to the β-products. Furthermore, according to the ^{1}H NMR spectra, the trans isomers were exclusively obtained. The *E* configuration of the double bond was confirmed by a coupling constant of ca. 16 Hz for the AB system corresponding to the vinyl hydrogens in the ^{1}H NMR spectrum. The rest of the expected signals were observed as well in the ^{1}H NMR spectra. The FTIR of fullerene derivatives showed the presence of the typical strong band at around 1715 m^{-1} corresponding to the ester group. In addition, all the structures of fullerene derivatives **5a**–**d**[20] and **6a**–**b** were confirmed by their MALDI-TOF mass spectra, which showed the expected molecular ions.

Table 1

Reaction conditions and yields for reactions between **1** and **3** and acrylates **4a**–**d** under microwave irradiation[a]

Entry	Fullerene aryl halide	Acrylate R	Time (h)	Product	Yield (%)
1	**1**	**4a**	4.5	**5a**	44
2	**1**	**4b**	4.5	**5b**	52
3	**1**	**4c**	4.5	**5c**	48
4	**1**	**4d**	4.5	**5d**	34
5	**2**	**4a**	3	**6a**	41
6	**2**	**4b**	3	**6b**	42
7	**3**	**4c**	13.5	**5c**	5

[a] Reactions performed in sealed Pyrex tubes under argon, using 10 mL of chlorobenzene as solvent. Continuous irradiation (2450 Hz). Power: 300 W.



Scheme 2.

It should be commented that the reaction of other alkenes (styrene or acrolein) with pyrrolidino[60] fullerene halide **1** did not lead to any identifiable product, with the fullerene derivative recovered and massive polymerization of the alkenes observed.

Pressurized microwave reactors have shown significant advantages in synthesis.[21] Indeed, the reaction between **1** and **4a** was performed under pressure (300 W, 38 psi, 135 °C) (Fig. 1) in a focused microwave reactor in 1,2-dichloroethane, a solvent that absorbs microwave irradiation strongly. After 2.5 h, fullerene derivative **1** had been

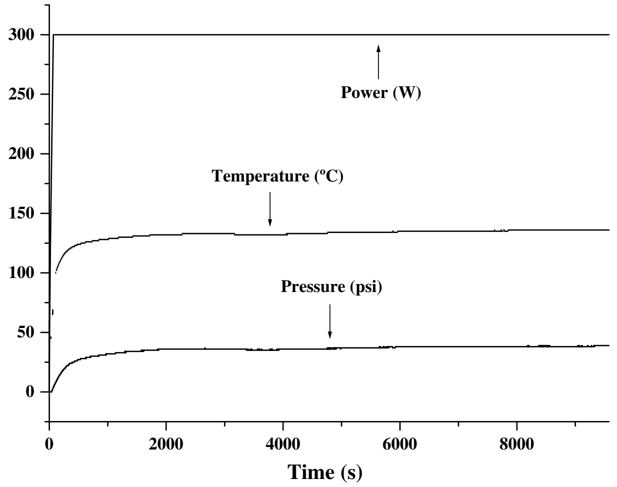


Fig. 1. Temperature, irradiation power and pressure profile of **6a** for pressurized microwave conditions. (300 W, 38 psi, 135 °C).

consumed and, after workup, compound **6a** was isolated in 34% yield—lower than that obtained at atmospheric pressure in chlorobenzene.

In conclusion, we have explored the Heck reaction on fullerene derivatives. Our results demonstrate the feasibility of introducing an alkene functionality at the periphery of the C_{60} cage through the Heck reaction on a fullerene derivative with an aryl iodide moiety. The efficiency of controlled microwave irradiation as the energy source to promote the Heck coupling in fullerene derivatives has been demonstrated.

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19. Typical procedure for palladium-catalyzed coupling reaction under microwave irradiation of **5b** (Table 1, entry 2). A heavy-walled glass vial (80 mL capacity) was charged under argon with fullerene aryl halide (**1**) (1 equiv) in chlorobenzene (10 mL), the corresponding acrylate (**4b**) (excess 1650 µL,) triethyl amine (21 µL), palladium acetate(II) (10 mol % with respect to C_{60} derivative), tri(*o*-tolyl)phosphine (4 equiv with respect to palladium (II)) were thereafter added. The vial was then heated to 132 °C by microwave irradiation at 300 W for 4.5 h. After cooling, the crude reaction mixture was extracted with CH_2Cl_2 (50 mL) and washed with water (50 mL). The organic layer was dried with $MgSO_4$ and the solvent was removed at reduced pressure. The residue was purified by chromatography using toluene and CH_2Cl_2. Centrifuging three times with methanol and once with n-pentane accomplished further purification of the solid.
20. *Selected spectroscopic data for* **5b**: yield: 52% (as a dark brown solid); FTIR (KBr) v_{max}/cm^{-1} 2929, 2855, 2781, 2342, 1715, 1634, 1464, 1176, 1036, 984 and 528; ^1H NMR ($CDCl_3$) δ/ppm 7.85 (2H, d, *J* 8.5 Hz), 7.68 (1H, B of AB system, d, *J* 16 Hz), 7.60 (2H, d, *J* 8.5 Hz), 6.46 (1H, A of AB system, d, *J* 16 Hz), 5.00 (1H, d, *J* 9.5 Hz), 4.97 (1H, s), 4.28 (1H, d, *J* 9.5 Hz), 4.27–4.18 (2H, m), 3.75–3.69 (2H, m), 2.82 (3H, s), 1.86–1.63 (4H, m); ^{13}C NMR ($CDCl_3$) δ/ppm 166.8, 153.8, 153.0, 147.3, 147.2, 146.5, 146.3, 146.2, 146.1, 145.9, 145.8, 145.7, 145.5, 145.4, 145.3, 145.2, 145.1, 144.7, 144.5, 144.4, 144.3, 144.1, 143.1, 142.9, 142.7, 142.6, 142.5, 142.2, 142.1, 142.0, 141.9, 141.8, 141.7, 141.5, 140.1, 139.8, 139.5, 136.9, 136.4, 135.9, 135.6, 134.5, 130.7, 130.6, 129.9, 129.8, 128.4, 128.3, 127.9, 120.3, 118.4, 83.2, 69.9, 69.0, 64.3, 62.4, 62.3, 40.0, 29.6, 29.1 and 25.0; UV–vis (CH_2Cl_2) λ_{max} (nm) (log ε): 227 (4.9), 256 (5.0), 431 (3.5); MALDI-TOF *m*/*z* 995.1833 (M^+).
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